Some Commutation Phenomena Of Direct Current Machinery

F. C. Clark

1905

SOME COMMUTATION PHENOMENA

of

DIRECT CURRENT MACHINERY.

Being a thesis presented

by

F. C. Clark.

for the degree

of

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Having completed the prescribed course in

Electrical Engineering

at

ARMOUR INSTITUTE OF TECHNOLOGY.

June first one thousand nine hundred and five.

C. E. Freeman
Professor

H. M. Raymond
Dean of Engineering Studies

L. C. Monin
Dean of Cultural Studies

Current Commutation.

Much attention has been given to the theory of commutation in direct current machinery but few attempts to measure the current flowing in the coil that,during commutation,is short-circuited are on record.

An attempt will be made in this paper to throw a little light on the subject of this measurment,and on the factors governing the magnitude and the law of variation of this current under different give conditions. The first,in importance,of these factors is that of contact resistance. By the term contact resistance is understood the resistance of the contact between the surface of the commutator and that of the brush. This contact resistance is the main factor in determining whether or not the current during short-circuit will or willnot be excessive in magnitude,and,in general has no bearing on the rate of change of the current.

The rate of change or shape of the wave of this current will depend on the self induction of the coil,the frequency of commutation and upon the electromotive forces induced in it at the different stages of commutation.

As this wave form is,at present,of secondary importance to the magnitude of the current I will first take up the questions of contact resistance.

For the purpose of determining this resistance under various

[illegible]

Much attention has been given in the [illegible]

direct current machines, [illegible]

flowing in the coil [illegible] commutation, [illegible]

and its [illegible]

[illegible]

on the subject of this [illegible]

the [illegible] of the [illegible]

[illegible]

[illegible] is that at [illegible]

[illegible]

the surface of the [illegible]

[illegible] in the [illegible]

and the current [illegible]

[illegible]

of change of the current.

[illegible]

[illegible]

[illegible] of the [illegible]

[illegible]

[illegible]

of [illegible]

For the [illegible]

[illegible]

conditions a commutator was mounted on a shaft running in bearings and equipped with a belt and pulley wheel. To remove all inductive effects this commutator was mounted without an armature and to secure the passage of a current from one segment to another, or others as the case may be, a brass ring was soldered to one end making good contact with each segment. This commutator was run by a variable speed motor and the resistance determined by the fall of potential method which required the following apparatus:-

1 Weston portable voltmeter (0 ÷ 5)

1 Weston portable ammeter (0 - 50)

1 Tachometer.

1 Lamp rack and source of supply current.

The apparatus was connected as shown in the scheme on the following page. The brushes used were of carbon in all cases, three grades being used and designated as follows:-

No. 1 Of medium fine grain and medium hardness

" 2 " " " " harder than No. 1.

" 3 " extemely fine grain and very soft.

Brushes Nos..1 and 2 were such as are met with in American current practice. No. 3 was of French manufacture and was more of a graphite composition than of ordinary carbon. The conductivity of No. 3 was almost four times as great as that

DIAGRAM OF CONNECTIONS

of Nos. 1 and 2,which were nearly equal.

The tests made on these brushes were to determine the relation of their contact resistance to the following conditions or qualities:-

1. Speed.
2. Temperature.
3. Current density.

A determination of their coefficient of friction was also made.

To determine the relation between the contact resistance and speed a series of runs were made in which a constant current-density was maintained in the brushes and the speed varied. At each variation of the speed readings were made on the tachometer,voltmeter and ammeter. The temperature in this case was kept as nearly constant as possible by running the commutator,before any reading was made,until the temperature ceased to rise. At various speeds varied amounts of heat were generated but owing to the slight amount of increase due to this no appreciable error was introduced.

The temperature effect of contact resistance was unsatisfactory from all points of view. The commutator was so large in proportion to the amount of heat generated in that its temperature was but slightly affected and external heating was resorted to. This was accomplished by means of incandescent

lights were placed under and within two inches of the commutator. This series of runs was made at constant speed and current and when the voltmeter showed an appreciably drop over the brushes and commutator readings of speed,current and potential drop were made and the commutator stopped. The temperature was taken by means of a thermometer placed on the surface of the commutator and covered with waste.

The third set of runs,made at constant speed with variable current density,were made by running the commutator at a given speed with maximum current until a constant temperature had been reached,then the current was reduced and readings immediately taken on all instruments. With this precaution I beleive that temperature errors were practically eliminated. After each set of readings the current was raised to full value and allowed to remain there three minutes before it was again reduced in order to obtain readings.

The brush rigging was mounted so that it could be free to rotate,in order to obtain the coefficient of friction. The method of doing this was to balance the torque,exerted on it by the brushes,by a spring balance. Readings were made for various brush tensions and commutator speeds.

The brush tension in all the following data was one and a half pounds per square inch except in cases where noted. This

brush tension was obtained by means of a spring balance.

The curves for any set of data are on the page or pages immediately following it. When two sets of data occur on one page the first curve met with will be plotted from the first set of data on that page.

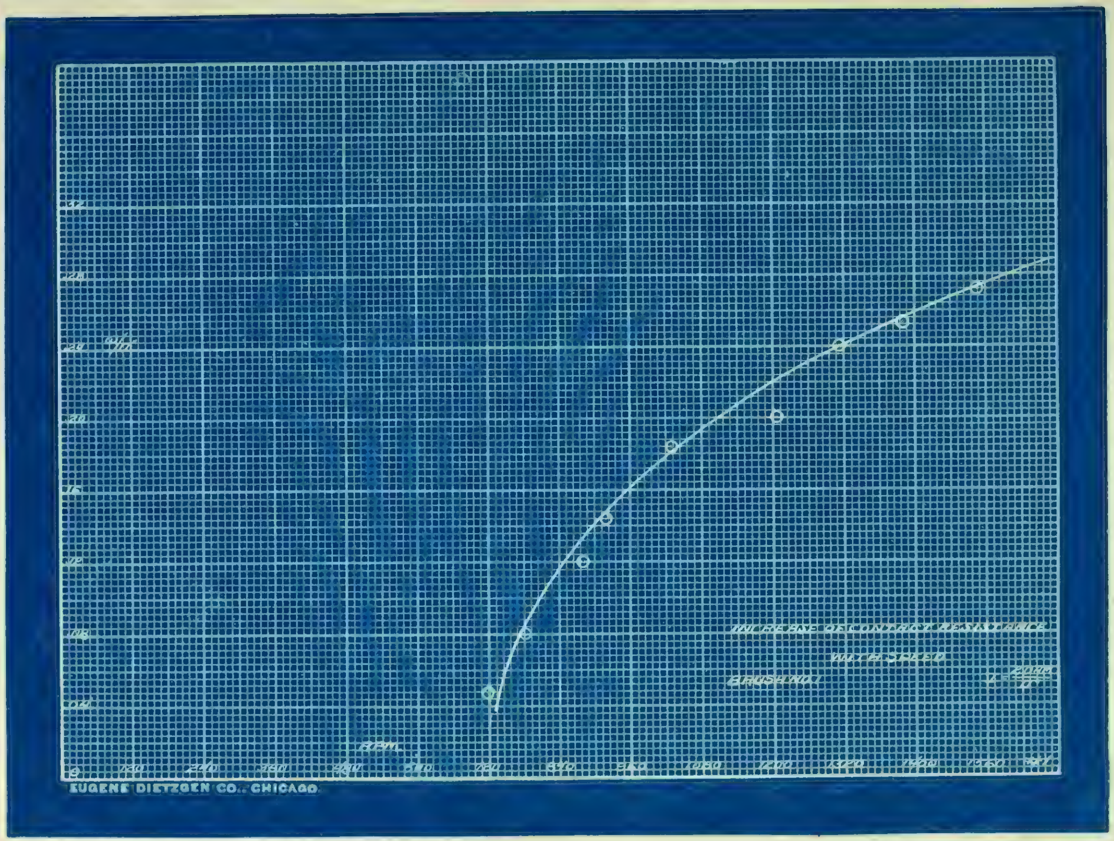
Before each run care was taken to see that the brush was fitted to the surface of the commutator. In cases where the brush did not bear all over its surface it was ground to the contour of the commutator in the usual manner with fine sand-paper and the marks of the sand-paper removed by running the commutator for some time before the readings were started. The surface of the commutator was smooth and well polished in all cases.

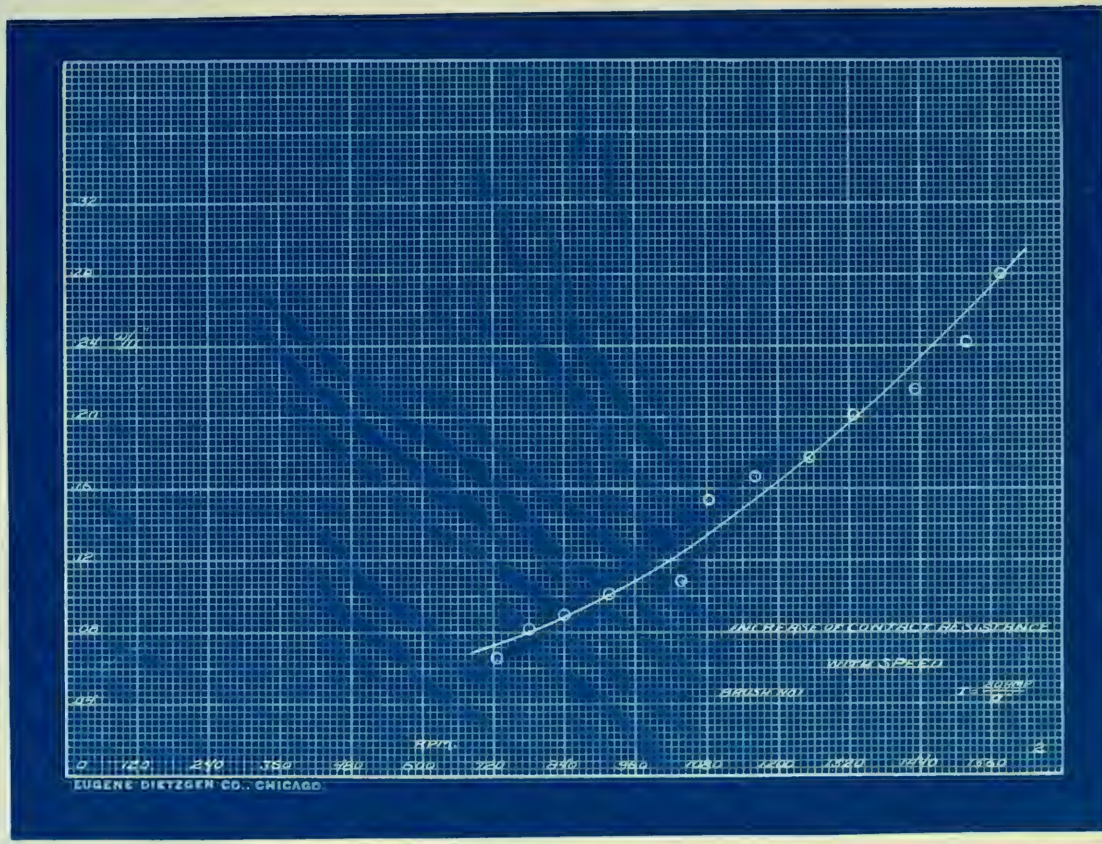
#1.

Tach.	R.P.M.	E.	I.	R.	R/□"
0	0	0/60	12.	0.05	.004
59	720	0.75	"	0.06	.048
64	780	1.20	"	0.10	.08
72	880	1.80	"	0.15	.120
76	932	2.20	"	0.18	.144
85	1040	2.80	"	0.23	.184
100	1208	3.10	"	0.25	.200
109	1315	3.70	"	0.30	.240
118	1422	3.90	"	0.32	.256
131	1608	4.10	"	0.34	.272

#2.

Tach.	R.P.M.	E.	I.	R.	R/□"
0	0	0.25	12.5	0.02	.016
60	728	1.00	12.0	0.08	.064
65	792	1.20	"	0.10	.08
69.5	850	1.30	"	0.11	.088
75	920	1.50	"	0.125	.100
85	1040	1.60	"	0.133	.1064
90	1087	2.30	"	0.192	.1536
98	1183	2.50	"	0.208	.1664
104	1256	2.65	"	0.220	.1760
110	1328	3.10	"	0.250	.2000
118	1434	3.20	"	0/268	.2144
123	1516	3.60	"	0.3000	.2400
128	1576	4.20	"	0.350	.2800


RPM
EUGENE DIETZGEN CO., CHICAGO

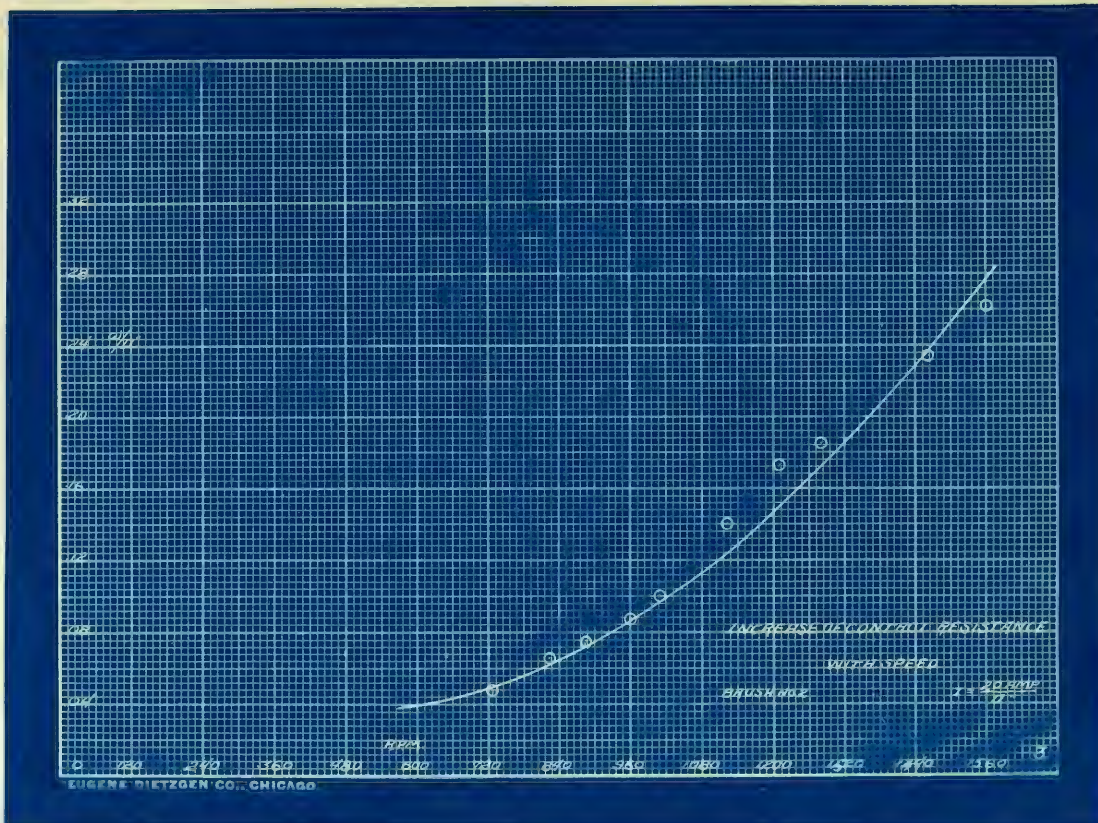

INCREASE OF CONTACT RESISTANCE
WITH SPEED
BRUSH NO1
R.P.M.
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560
EUGENE DIETZGEN CO., CHICAGO.

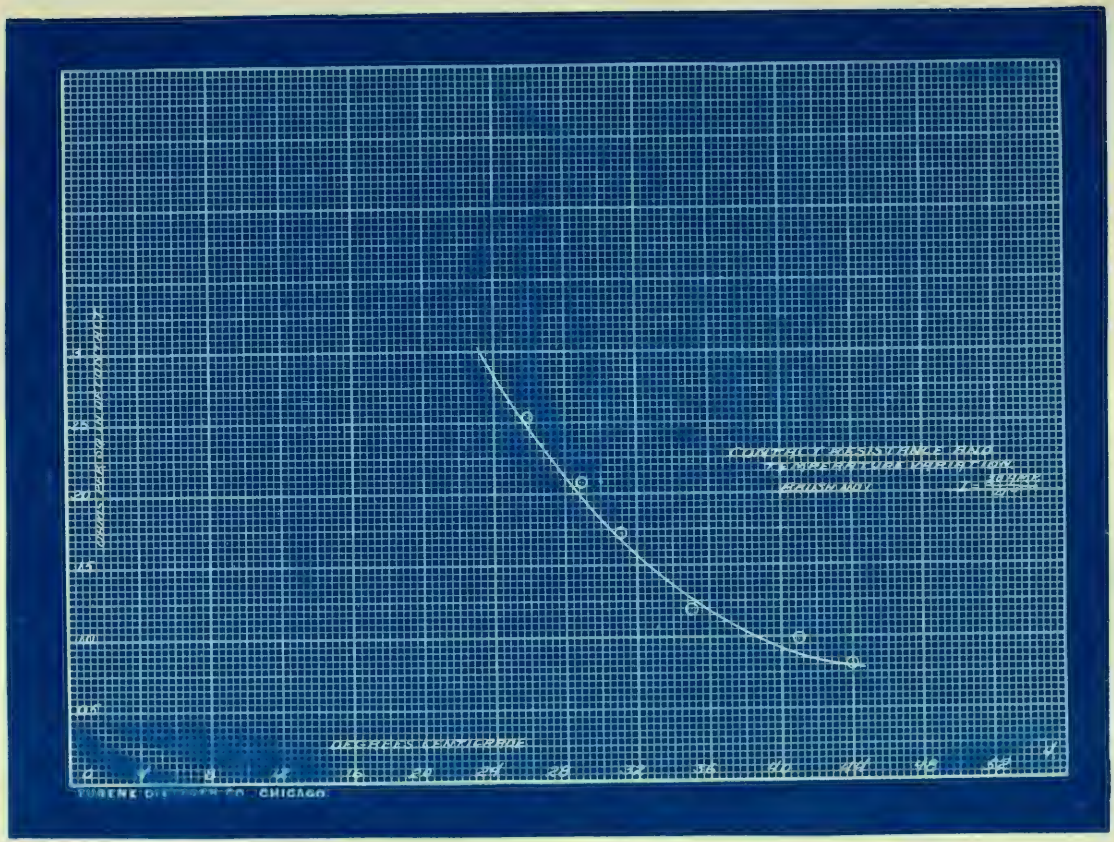
#3.

Tach.	R.P.M.	E.	I.	R.	R/□"
0.	0.	0.32	12.0	0.025	0/020
60.	728.	0.70	"	0.058	0.0464
67.	820.	1.00	"	0.083	0.0664
72.	880.	1.10	"	0.091	0.0728
78.	960.	1.30	"	0.108	0.0864
84.	1012.	1.50	"	0.125	0.1000
92.	1126	2.10	"	0.176	0.1408
100.	1208.	2.60	"	0.217	0.1736
105.	1280.	2.75	"	0.229	0.1832
120.	1480.	3.50	"	0.291	0.2328
128.	1564.	3.60	"	0.330	0.2640

#4.

I.	RI.	T.	R.P.M.	Time.	R.	R/ ".
10.5	3.30	26.	1000.	10:34	0.314	0.2512
"	3.00	29.	"	:37	0/285	0.2080
"	2.25	31.	1612.	:40	0.214	0.1712
"	1.60	35.	"	:48	0/145	0.1160
10.0	1.37	36.	"	11:07	0.137	0.1096
10.5	1.30	41.	"	:20	0.123	0.0984
10.0	1.00	44.	"	:40	0.100	0.0800


INCREASE OF CONTACT RESISTANCE
WITH SPEED
BRUSH No 2
RPM
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
.04
.08
.12
.16
.20
.24
.28
.32
EUGENE DIETZGEN CO. CHICAGO

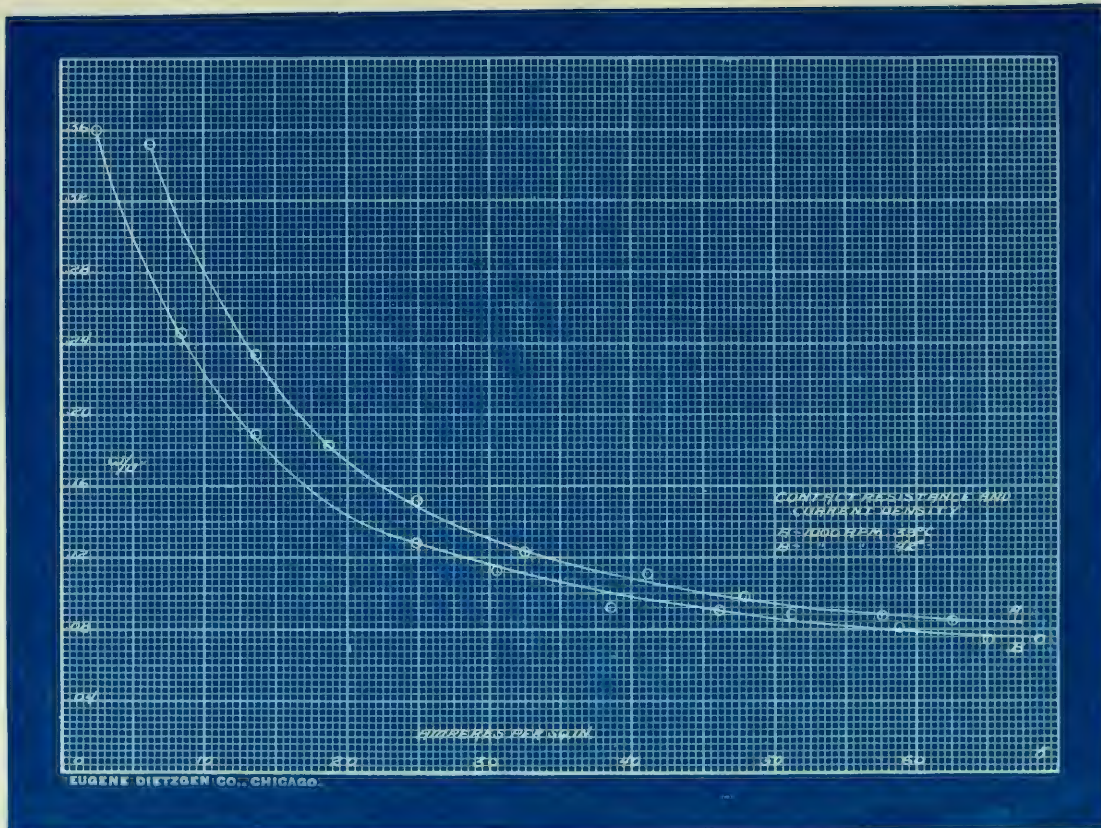

CONTACT RESISTANCE AND
TEMPERATURE VARIATION
DEGREES CENTIGRADE
0
4
8
12
16
20
24
28
32
36
40
44
48
52
.10
.15
.20
.25
CHICAGO

#5.

I.	RI.	T.	R.P.M.	R.	R/ ".
1.00	0.45	42.	1000.	0.45	0.3600
3.25	1.00	"	"	0.307	0.2456
5.50	1.30	"	"	0.236	0.1888
7.50	1.45	"	"	0.253	0.2024
10.00	1.60	"	"	0.160	0.1280
12.25	1.75	"	"	0.142	0.1136
15.50	1.90	"	"	0.116	0.0928
18.50	2.10	"	"	0.113	0.0914
20.50	2.20	"	"	0.110	0.0880
23.50	2.45	"	"	0.104	0.0832
26.00	2.40	"	"	0.0919	0.0736
27.50	2.50	"	"	0.0909	0.0727

#6.

I.	RI.	T.	R.P.M.	R.	R/ ".
2.50	1.10	39.	1000.	0.440	0.352
5.50	1.60	"	"	0.290	0.232
7.50	1.70	"	"	0.216	0.1728
10.00	1.90	"	"	0/190	0.1520
13.00	2.00	"	"	0.153	0.1224
16.50	2.25	"	"	0.136	0.1088
19.25	2.35	"	"	0/122	0.0976
23.00	2.50	"	"	0.109	0.0872
25.25	2.60	"	"	0.102	0.0~~760~~
27.50	2.60	"	"	0/095	0.0760
30.50	2.80 2.75	"	"	0.0910	0.0728

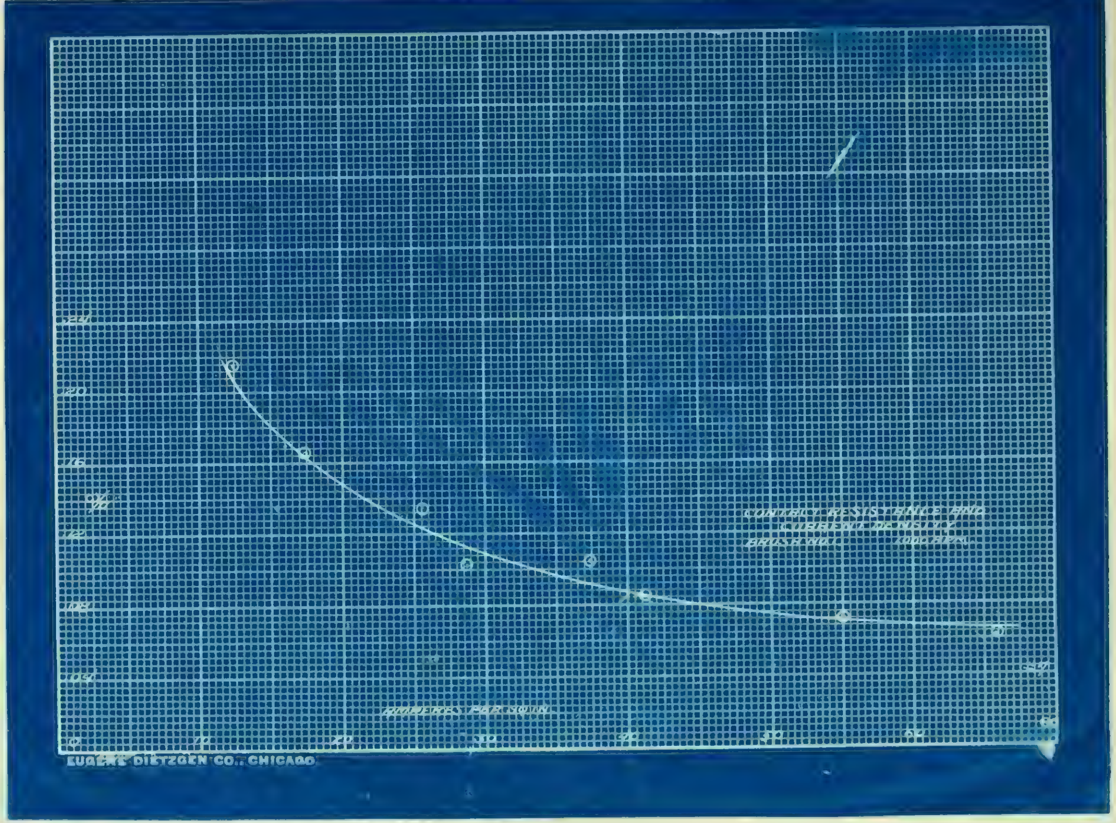

CONTACT RESISTANCE AND
CURRENT DENSITY
AMPERES PER SQ. IN.
.36
.32
.28
.24
.20
.16
.12
.08
.04
0
10
20
30
40
50
60
70
EUGENE DIETZGEN CO., CHICAGO.

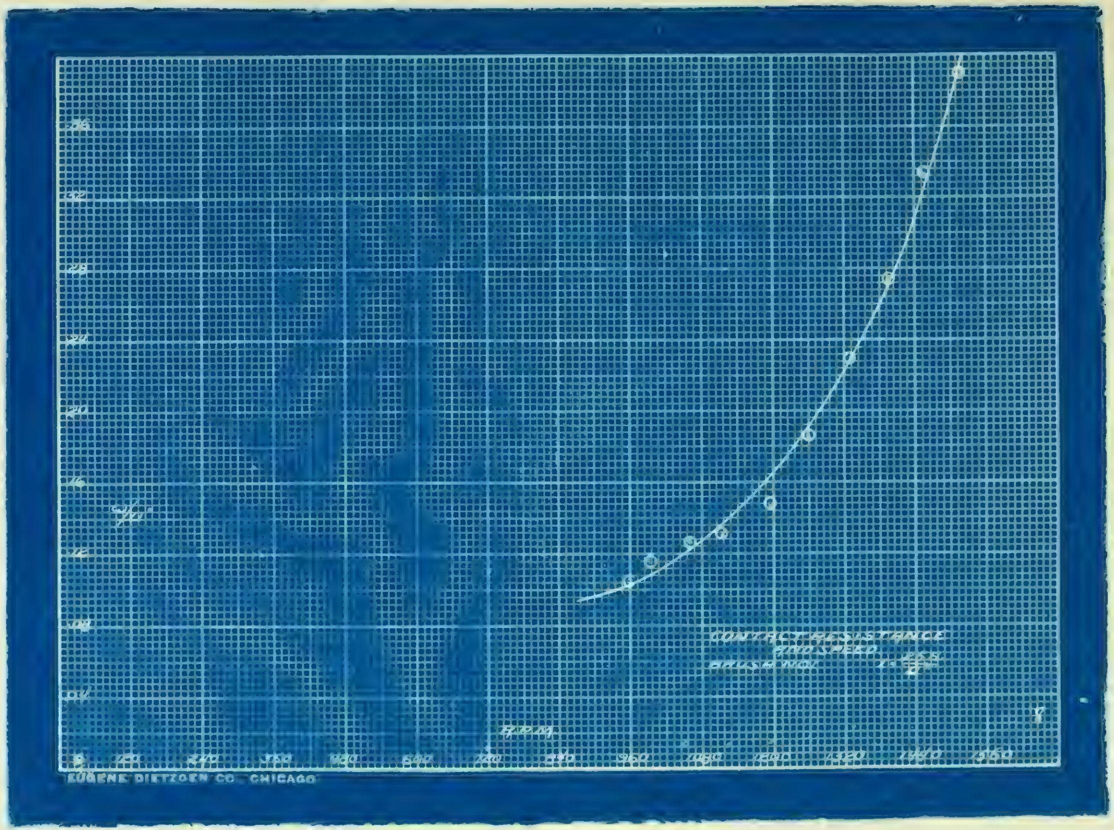
#7.

I.	RI.	S.	R.	R/ ".
1.00	0.75	860.	0.7500	0.60000
2.25	1.00	"	0.4500	0.36000
5.00	1.35	"	0.27000	0.21600
7.00	1.50	"	0.2100	0.16800
11.50	1.60	"	0.1300	0.10400
16.50	1.75	"	0.1060	0.08480
22.00	2.00	"	0.0909	0.07272
26.75	2.20	"	0.0820	0.06560

#8.

12.5	1.75	720.	0.140	0.1120
"	1.70	900.	0.130	0.1040
"	1.85	990.	0.148	0.1184
"	1.95	1060.	0.1560	0.1248
"	2.00	1115.	0.160	0.1280
"	2.25	1197.	0.180	0.1440
"	2.90.	1260.	0.232	0.1856
"	3.60	1330.	0.288	0.2304
"	4.25	1395.	0.344	0.2752
"	5.25	1460	0.420	0.3360
"	6.20	1520	0.490	0.3920
"	7.10	1590.	0.560	0.4480


CONTACT RESISTANCE AND
CURRENT DENSITY
AMPERES PER SQ. IN.
.24
.20
.16
.12
.08
.04
0
10
20
30
40
50
60
EUGENE DIETZGEN CO., CHICAGO

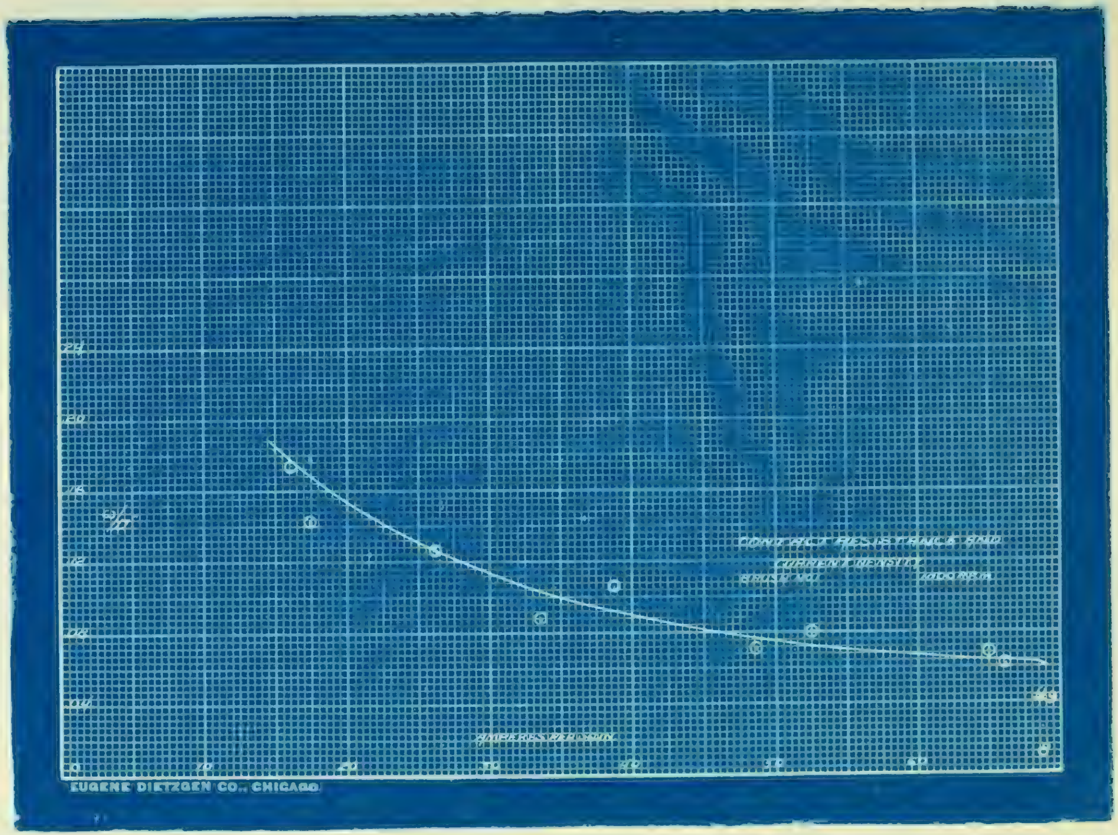

CONTACT RESISTANCE
AND SPEED
R.P.M.
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
EUGENE DIETZGEN CO. CHICAGO

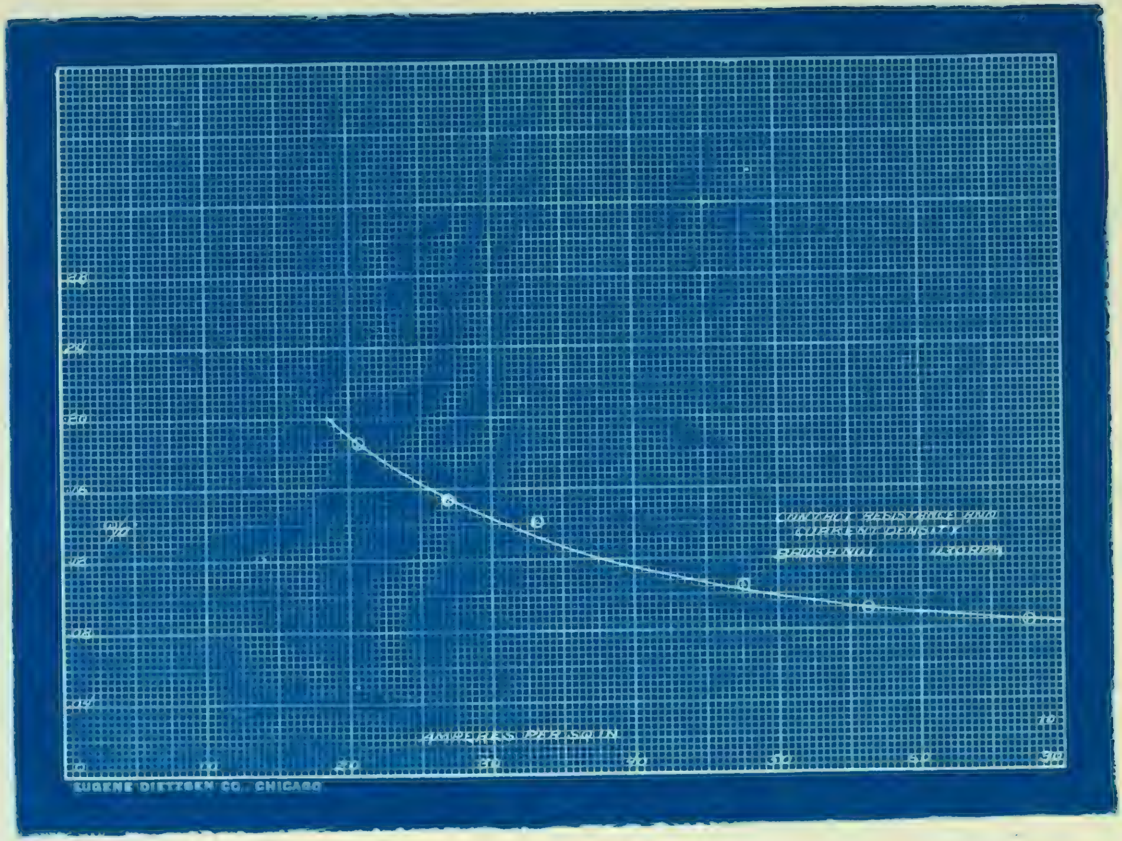
#9.

I.	RI.	S.	R.	R/ ".
3.5	1.00	1000.	0.234	0.1872
6.5	1.40	"	0.215	0.1720
7.0	1.25	"	0.178	0.1404
10.5	1.70	"	0.161	0.1288
13.5	1.50	"	0.111	0.0888
19.5	1.75	"	0.090	0.0720
26.5	2.00	"	0.0754	0.06032
31.0	2.20 2.50	"	0.0709	0.05672

#10.

3.25	1.50	1130.	0.460	0.3680
8.65	2.00	"	0.231	0.1848
10.75	2.10	"	0.196	0.1568
13.50	2.40	"	0.177	0.1416
19.00	2.50	"	0.131	0.1048
27.00	2.80	"	0.103	0.8240
22.50	2.65	"	0.117	0.0936
29.50	2.85	"	0.096	0.0768
30.50	3.00	"	0.098	0.0784


CONTACT RESISTANCE AND
CURRENT DENSITY
EUGENE DIETZGEN CO., CHICAGO



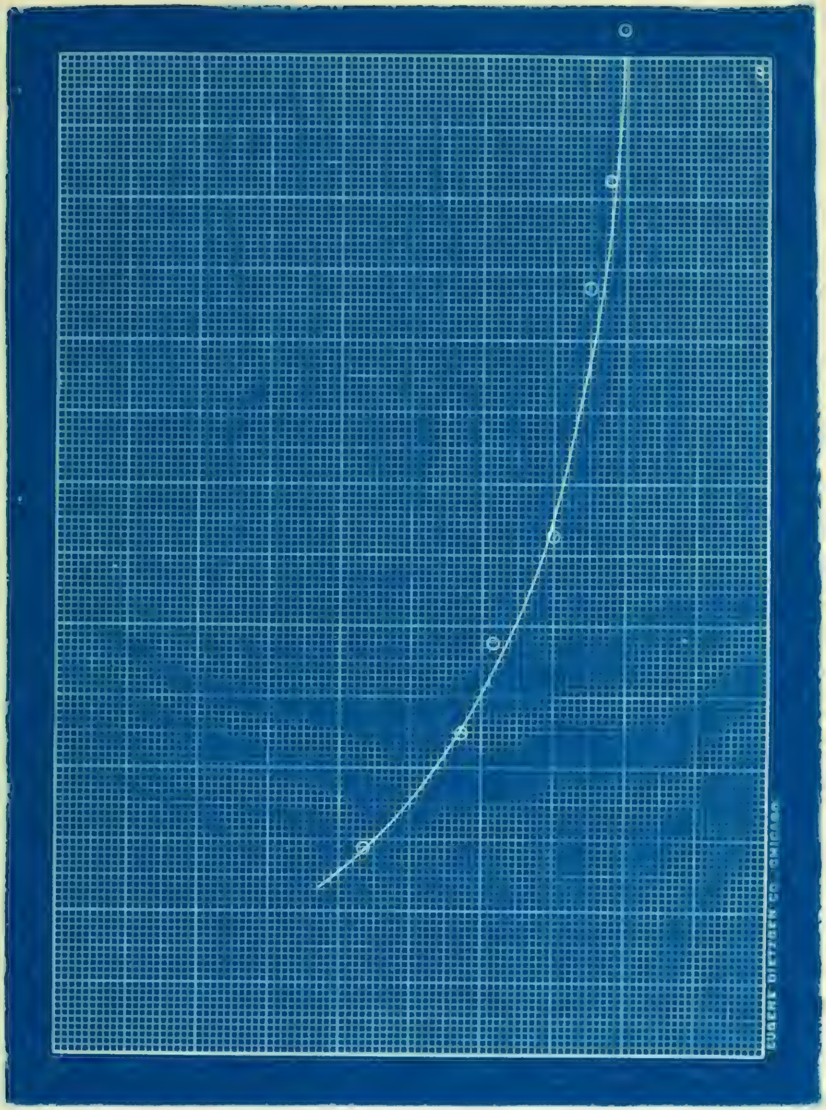
CONTACT RESISTANCE AND
CURRENT DENSITY
AMPERES PER SQ. IN.
EUGENE DIETZGEN CO. CHICAGO

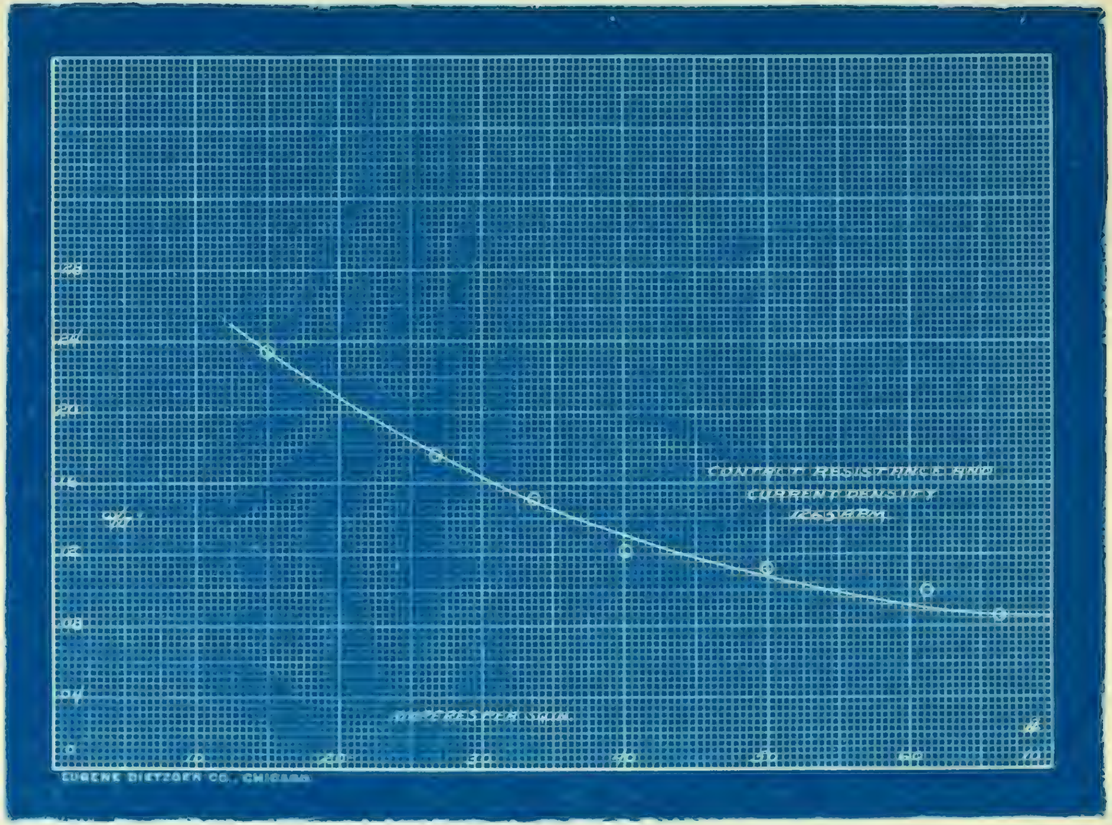
#11.

I.	RI.	R.P.M.	R.	R/ ".
5.75	1.65	1130.	0.280	0.2240
7.2	2.15	"	0.300	0.2400
9.00	1.90	"	0.210	0.1680
11.60	2.25	"	0.194	0.1552
14.50	2.30	"	0.150	0.1200
16.75	2.65	"	0.164	0.1412
21.50	2.70	"	0.125	0.1000
28.50	2.90	"	0.101	0.0808
31.40	3.00	"	0.0955	0.0764

#12.

I.	RI.	R.P.M.	R.	R/ ".
5.75	1.05	1265.	0.128	0.1456
9.60	1.40	"	0.145	0.1160
10.75	2.30	"	0.215	0.1720
13.50	2.65	"	0.196	0.1568
16.00	2.80	"	0.175	0.1200
20.75	2.95	"	0.142	0.1136
24.50	3.05	"	0.124	0.0992
28.60	3.20	"	0.105	0.0840
32.60	3.35	"	0.102	0.0916


EUGENE DIETZGEN CO. CHICAGO



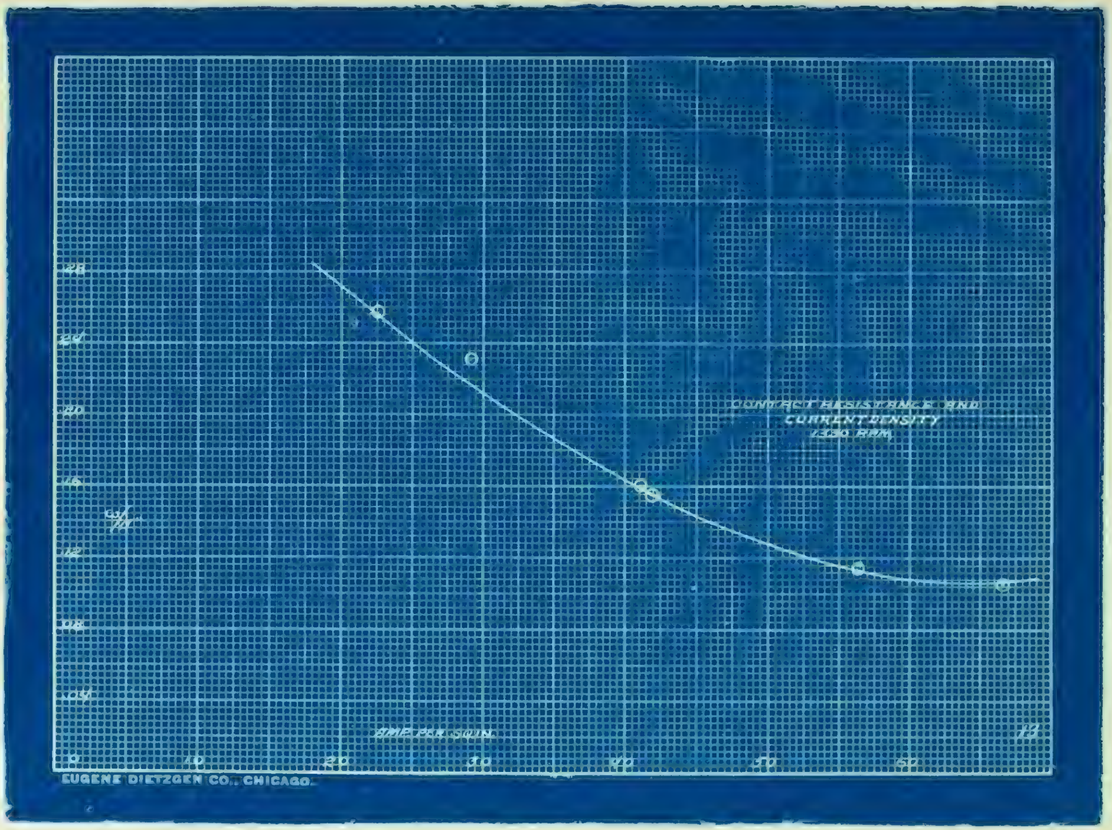
CONTACT RESISTANCE AND
CURRENT DENSITY
1265 R.P.M.
AMPERES PER SQ.IN.
.28
.24
.20
.16
.12
.08
.04
0
10
20
30
40
50
60
70
EUGENE DIETZGEN CO., CHICAGO

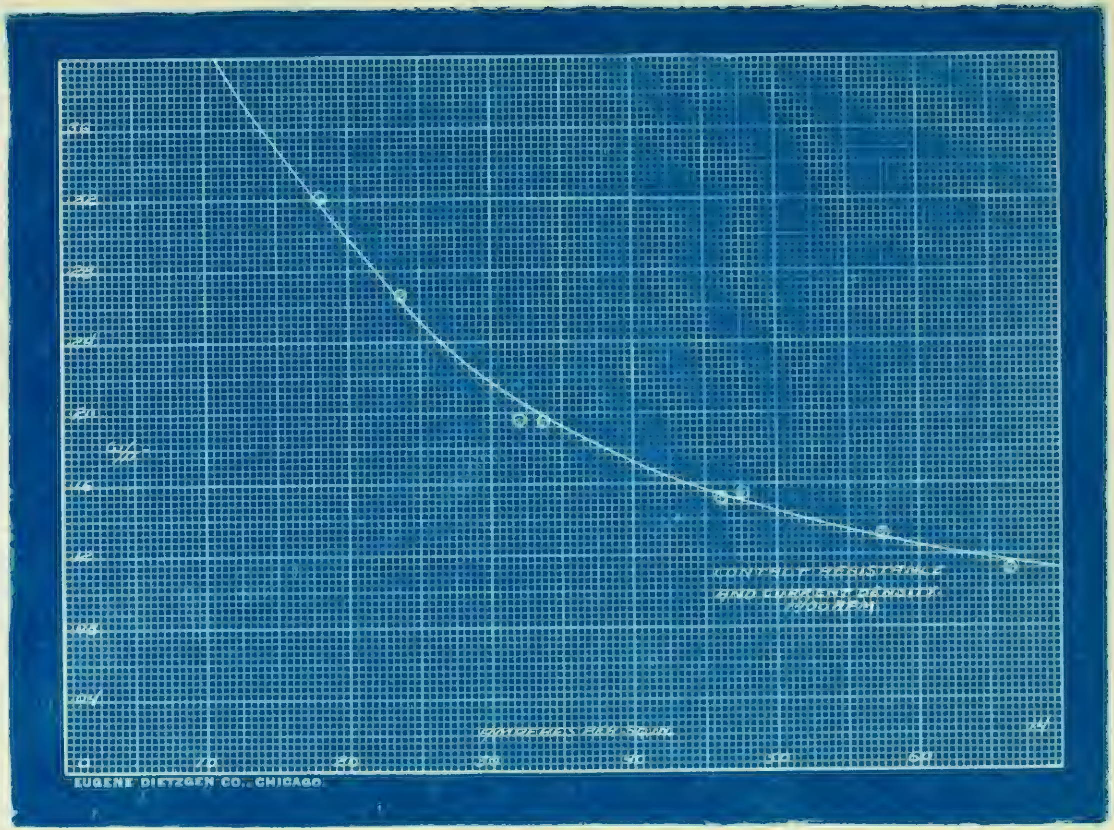
#13.

I.	RI.	R.P.M.	R.	R/ ".
3.60	2.10	1330.	0.600	0.4800
5.50	2.25	"	0.409	0.3672
8.25	2.70	"	0.320	0.2560
9.00	2.90	"	0.322	0.2576
11.75	3.10	"	0.264	0.2312
16.75	3.20	"	0.199n	0.1592
22.50	3.30	"	0.146	0.1168
26.70	3.48	"	0.130	0.1040
30.75	3.65	"	0.115	0.0920

#14.

I.	RI.	R.P.M.	R.	R/ ".
3.20	2.40	1400.	0.750	0.6000
7.25	2.90	"	0.400	0.3200
9.50	3.15	"	0.331	0.2648
13.75	3.40	"	0.248	0.1984
18.50	3.65	"	0.197	0.1576
19.00	3.65	"	0.192	0.1536
23.00	3.70	"	0.169	0.1352
26.50	3.75	"	0.141	0.1128
28.50	3.75	"	0.135	0.1080
30.60	3.85	"	0.125	0.1000


CONTACT RESISTANCE AND
CURRENT DENSITY
.28
.24
.20
.16
.12
.08
.04
0
10
20
30
40
50
60
AMP PER SQ IN
13
EUGENE DIETZGEN CO., CHICAGO.

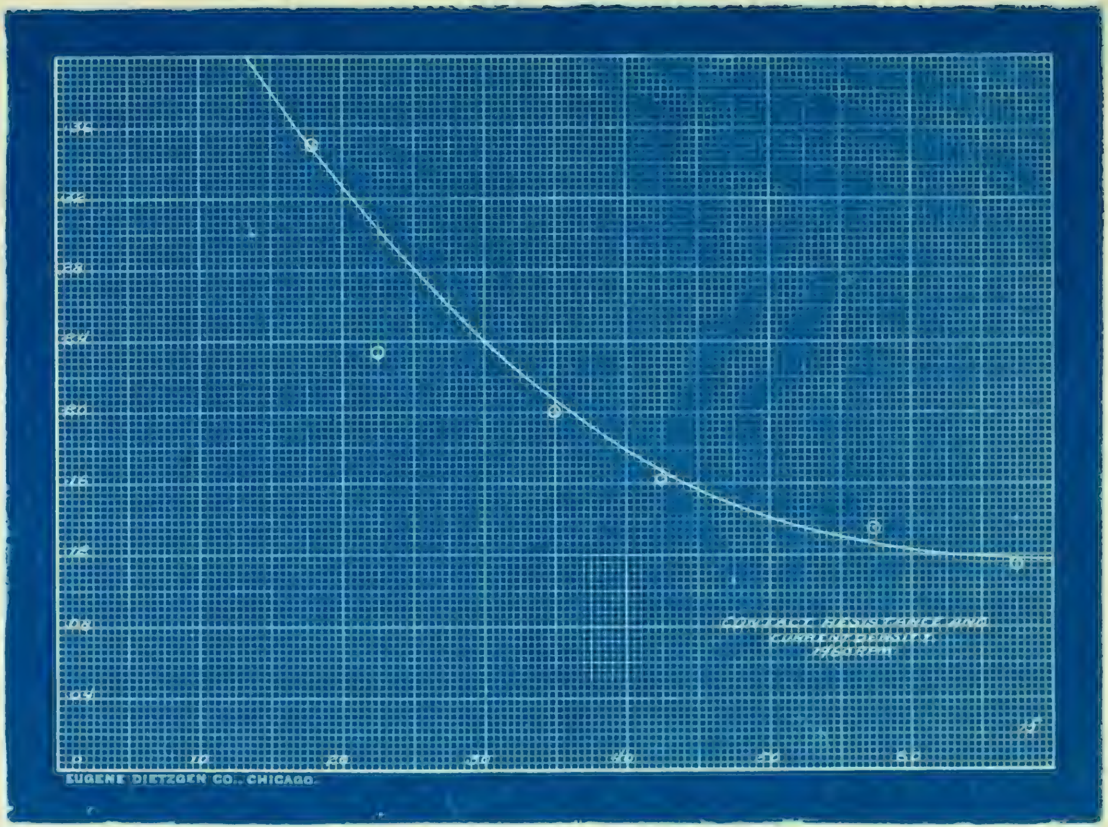

0
10
20
30
40
50
60
EUGENE DIETZGEN CO. CHICAGO

#15.

I.	RI.	R.P.M.	R.	R/ ".
5.50	3.0	1460.	0.540	0.4320
7.25	3.1	"	0.427	0.3516
9.00	3.3	"	0.366	0.2328
14.00	3.5	"	0.250	0.2000
19.00	3.5	"	0.131	0.1048
23.00	3.65	"	0.159	0.1273
27.00	3.80	"	0.140	0.1120
30.00	3.80	"	0.126	0.1008

#16.

I.	RI.	R.PM.	R.	R/ ".
4.25	3.20	1530.	0.727	0.5816
9.00	3.60	"	0.400	0.3200
11.00	3.75	"	0.340	0.2720
15.50	3.90	"	0.251	0.2008
20.50	4.00	"	0.195	0.1560
27.00	4.00	"	0.149	0.1192
31.00	4.20	"	0.135	0.1080


.36
.32
.28
.24
.20
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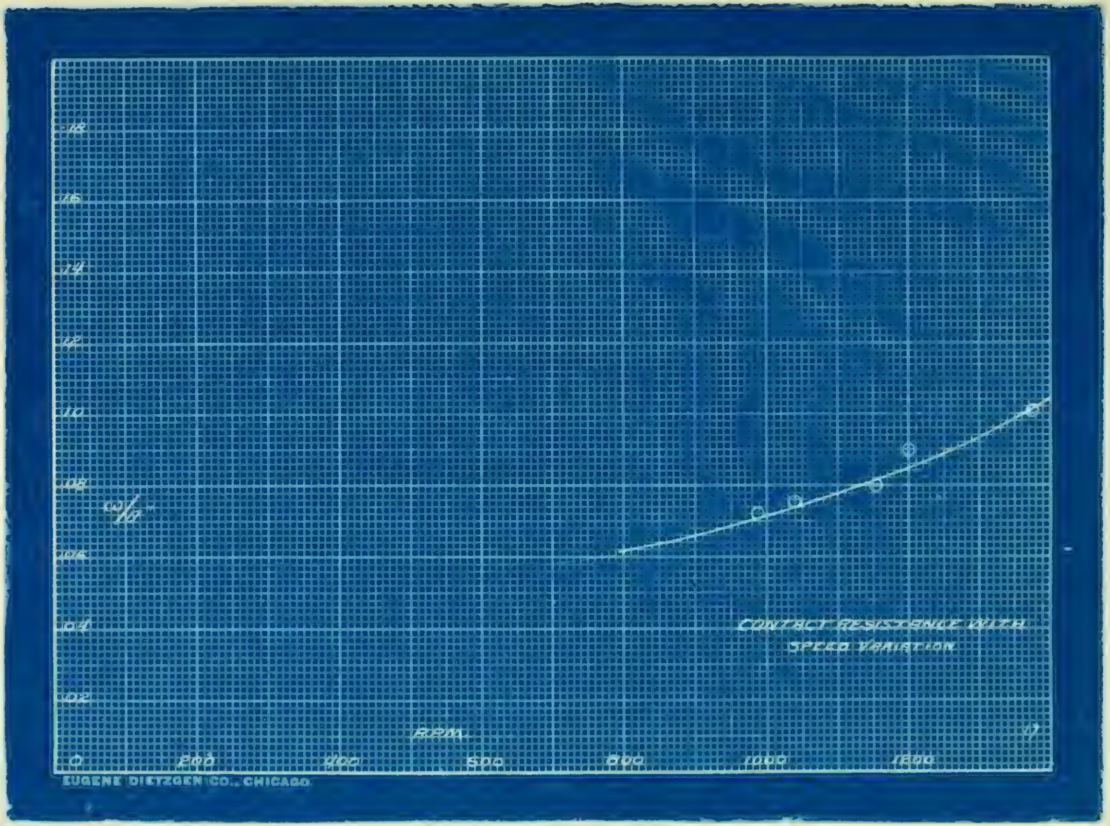
.08
.04
0
10
20
30
40
50
60
CONTACT RESISTANCE AND
CURRENT DENSITY.
EUGENE DIETZGEN CO., CHICAGO.

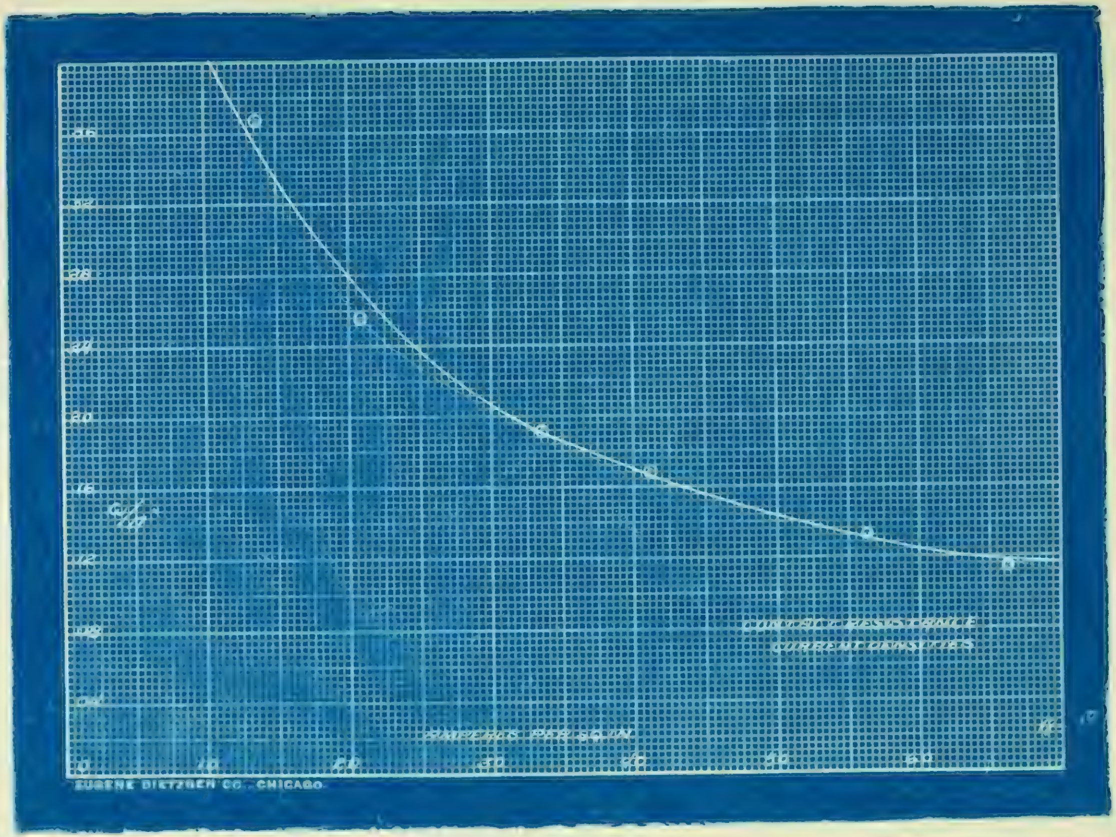
#17.

I.	RI.	R.P.M.	R.	R/ ".
30.0	2.75	990.	0.916	0.7328
"	2.90	1045.	0.966	0.7728
"	3.00	1156.	0.100	0.0800
"	3.40	1200.	0.113	0.0904
"	3.90	1275.	0.130	0.1040
29.0	4.20	1350.	0.144	0.1152
"	5.00	1425.	0.172	0.1376
"				

#18.

I.	RI.	R.P.M.	R.	R/ ".
3.5	1.90	900.	0.542	0.4336
5.5	2.25	"	0.409	0.3672
8.25	2.75	"	0/333	0.2554
13.50	3.25	"	0.241	0.1928
16.50	3.50	"	0.212	0.1696
22.50	3.70	"	0.164	0.1312
26.50	3.80	"	0.143	0.1144
29.00	4.00	"	0.138	0.1104


CONTACT RESISTANCE WITH
SPEED VARIATION
R.P.M.
0
200
400
600
800
1000
1200
.18
.16
.14
.12
.10
.08
.06
.04
.02
EUGENE DIETZGEN CO., CHICAGO



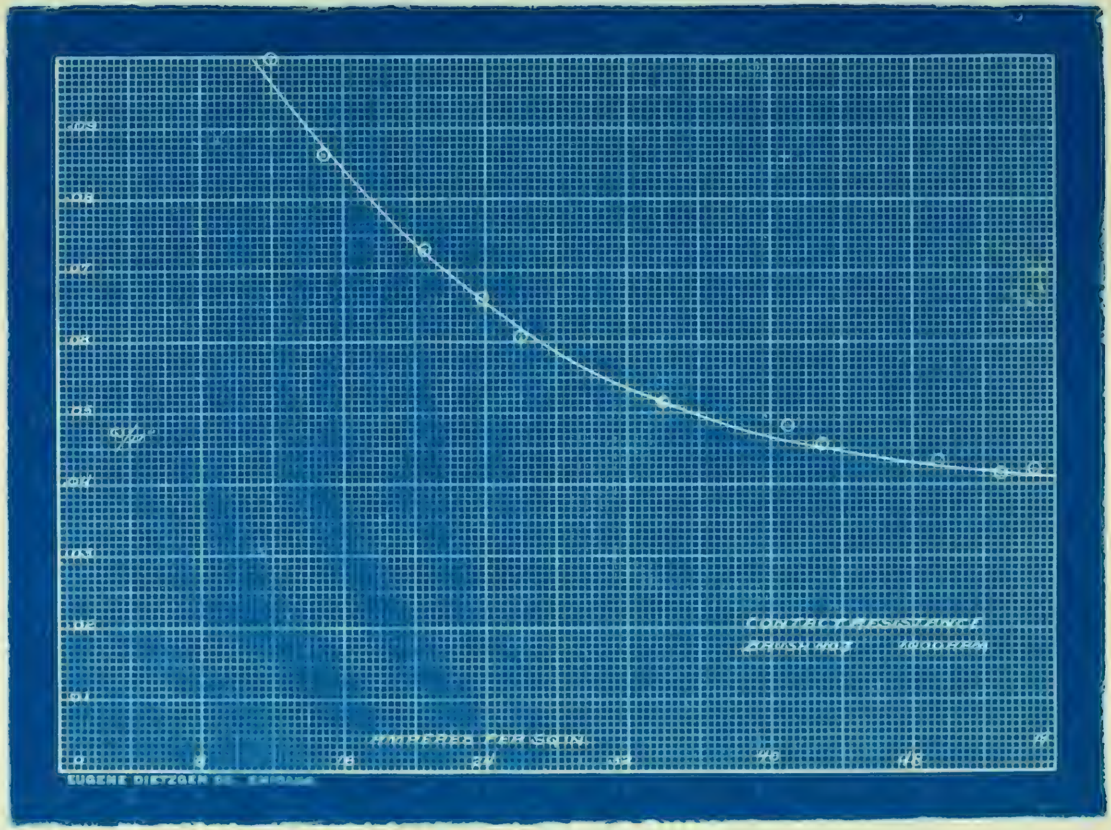
36
32
28
24
20
16
12
AMPERES PER SQ. IN.
0
10
20
30
40
50
60
EUGENE DIETZGEN CO. CHICAGO

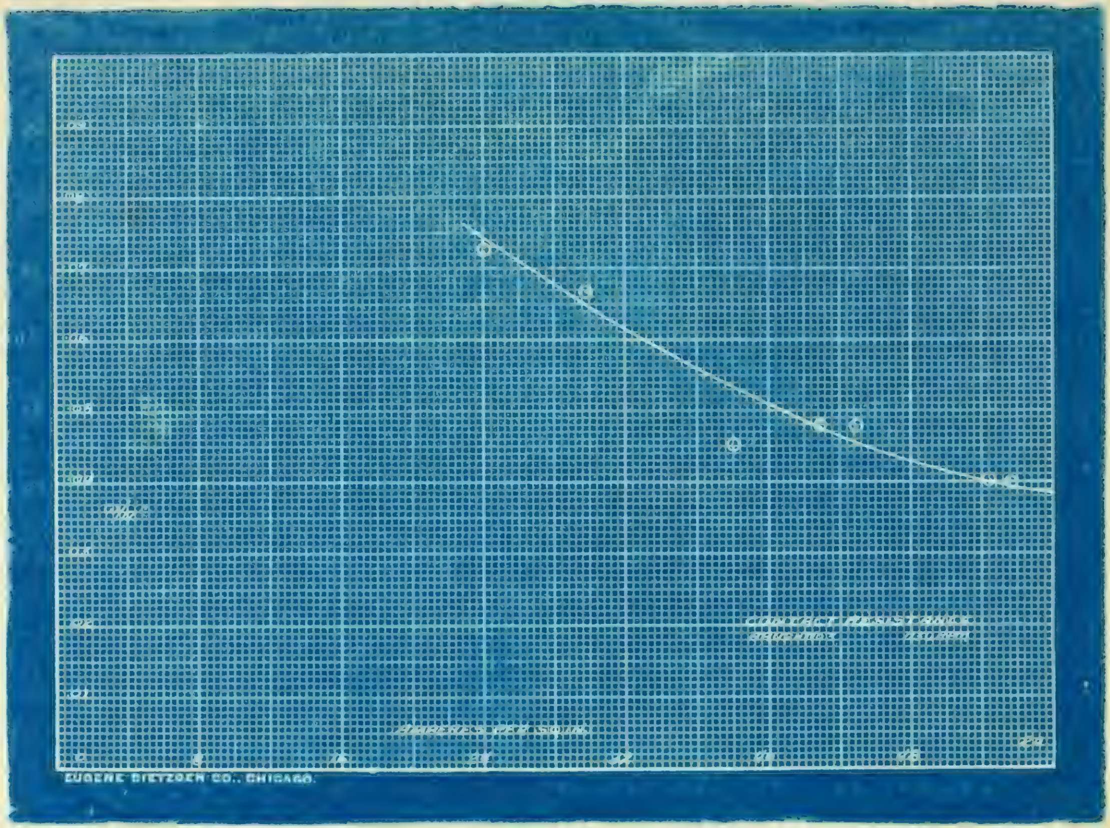
#19.

I.	RI.	R.P.M.	R.	R/ ".
6.00	1.20	1000.	0.200	0.1000
7.5	1.30	"	0.173	0.0886
10.25	1.50	"	0.146	0.0730
12.00	1.60	"	0.133	0.0515
15.00	1.80	"	0.120	0.0600
17.00	1.75	"	0.103	0.0515
20.50	2.00	"	0.0975	0.0487
21.50	2.00	"	0.093	0.0460
25.50	2.20	"	0.087	0.0436
26.50	2.20	"	0.083	0.0416
27.50	2.30	"	0.084	0.0420
30.00	2.50	"	0.083	0.0415

#20.

I.	RI.	R.P.M.	R.	R/ ".
12.00	1.75	1130.	0.145	0.0720
15.00	1.90	"	0.134	0.0670
19.00	1.70	"	0.090	0.0450
21.50	2.10	"	0.097	0.0480
22.50	2.20	"	0.097	0.0480
26.25	2.30	"	0.080	0.0400


.09
.08
.07
.06
.05
.04
.03
.02
.01
0
8
16
24
32
40
48
56
AMPERES PER SQ. IN.
CONTACT RESISTANCE
BRUSH NO. 7   1000 R.P.M.
EUGENE DIETZGEN CO. CHICAGO

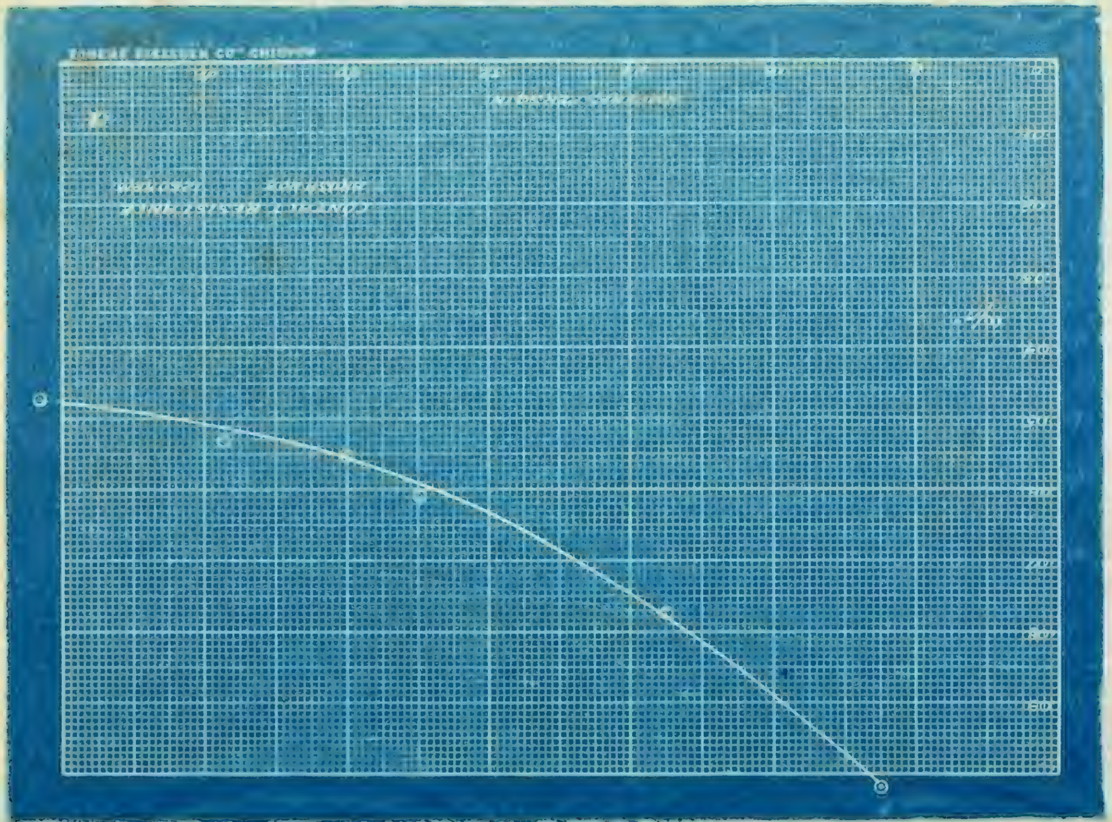

EUGENE DIETZGEN CO., CHICAGO.

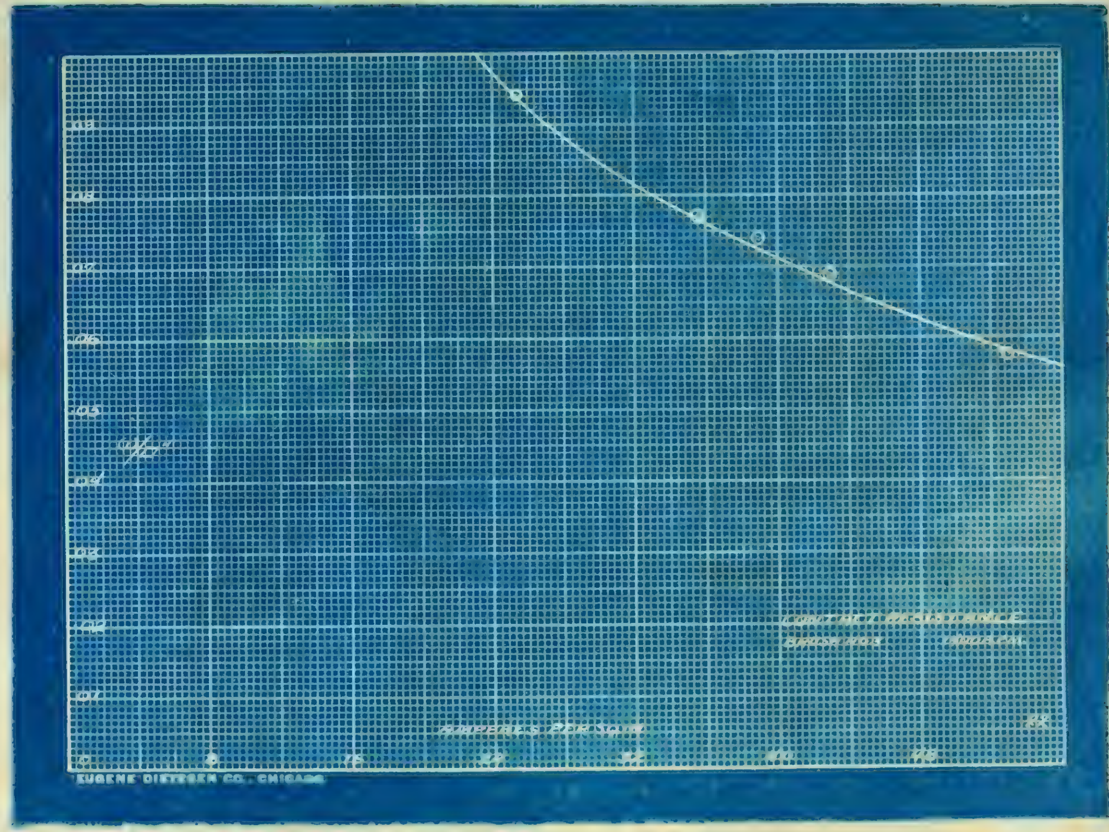
#21.

I.	Rl.	R.P.M.	R.	R/ ".
5.0	1.2	1260.	0.240	0.120
11.0	1.7	"	0.154	0.077
18.0	2.2	"	0.122	0.061
20.0	2.2	"	0.110	0.055
23.5	2.5	"	0.106	0.053
28.5	2.7	"	0..95	0.047
30.5	2.7	"	0.088	0.044

#22.

I.	Rl.	R.P.M.	R.	BR/ ".
5.00	2.0	1400.	0.400	0.200
10.5	2.3	"	0.219	0.109
17.75	2.8	"	0.154	0.077
19.50	2.9	"	0.148	0.074
21.50	3.0	"	0.139	0.069
26.50	3.1	"	0.117	0.058
31.50	3.2	"	0.101	0.050



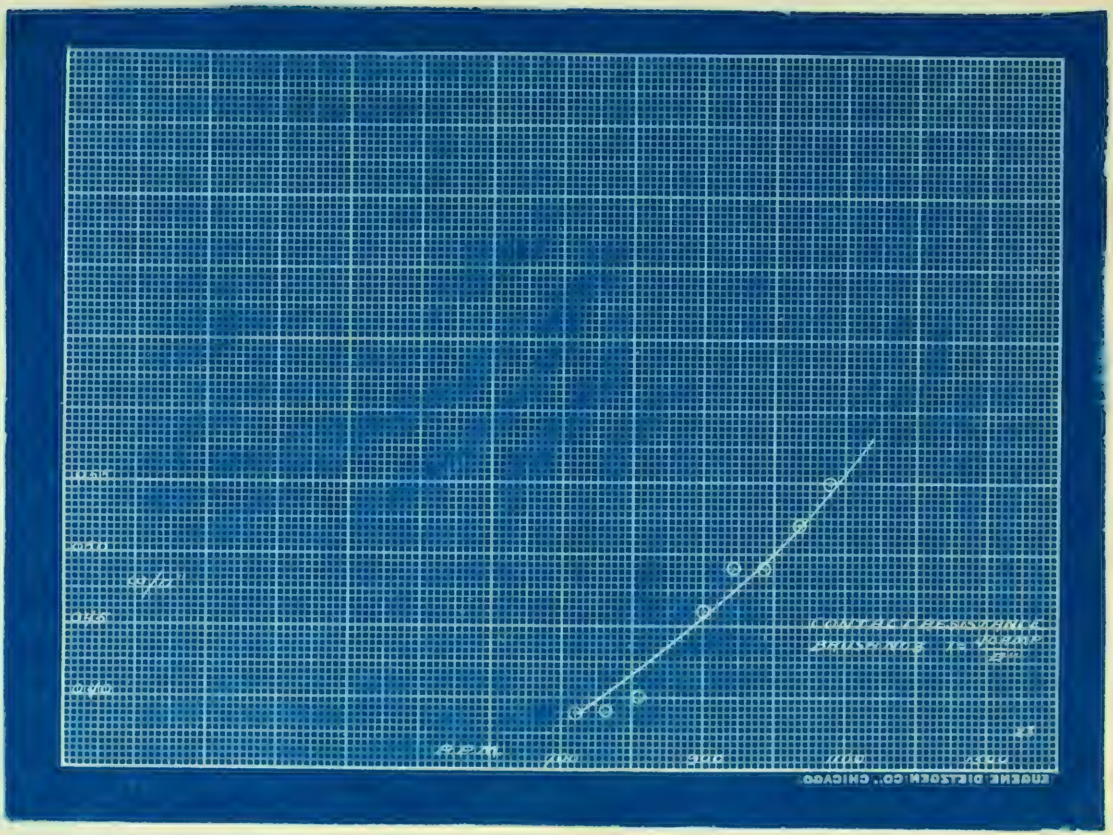

CONTACT RESISTANCE
AMPERES PER SQ. IN.
EUGENE DIETZGEN CO. CHICAGO

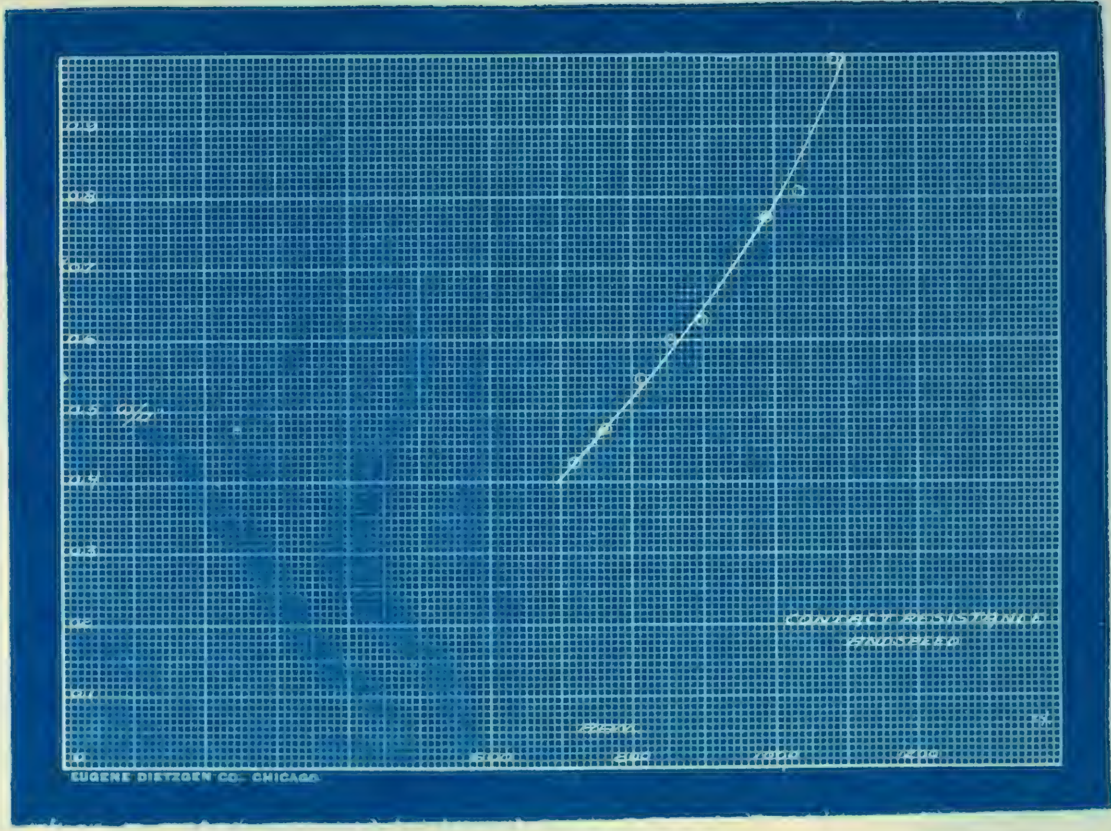
#23.

I.	RI.	R.	R/ ".	R.P.M.
29.5	2.25	0.079	0.039	720.
"	2.30	0.078	0.039	765.
"	2.40	0.081	0.040	810.
"	2.40	0.081	0.040	855.
"	2.75	0.093	0.046	900.
"	2.90	0.098	0.049	945.
"	2.90	0.098	0.049	990.
"	3.10	0.105	0.052	1035.
"	3.25	0.110	0.055	1080.

#24.

I.	R.I.	R.	R/ ".	R.P.M.
17.5	1.5	0.085	0.0425	720.
"	1.7	0.097	0.0485	765.
"	1.9	0.109	0.0545	810.
"	2.1	0.120	0.0600	855.
"	2.2	0.125	0.0625	900.
"	3.0	0.200	0.1000	945.
"	2.7	0.155	0.0775	990.
"	2.9	0.160	0.0800	1035.
"	3.0	0.200	0.1000	1080.


CONTACT RESISTANCE
EUGENE DIETZGEN CO. CHICAGO

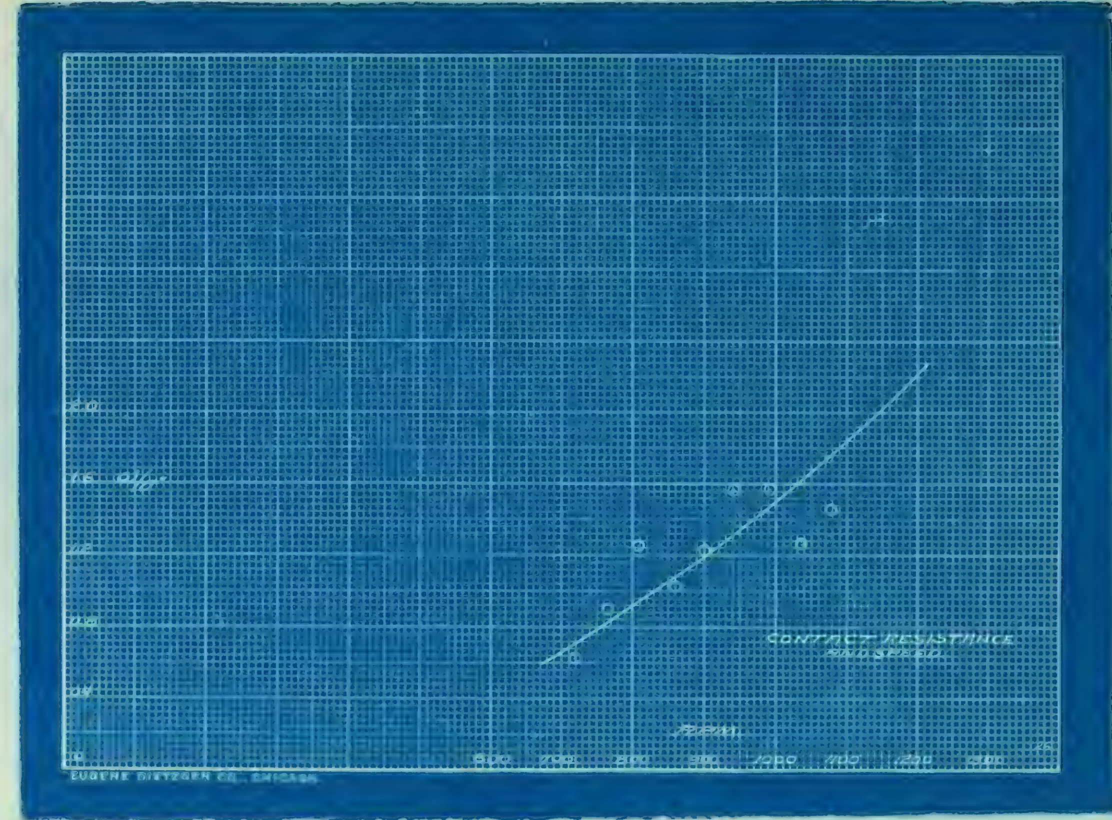

CONTACT RESISTANCE
600
800
1000
1200
EUGENE DIETZGEN CO. CHICAGO

#25.

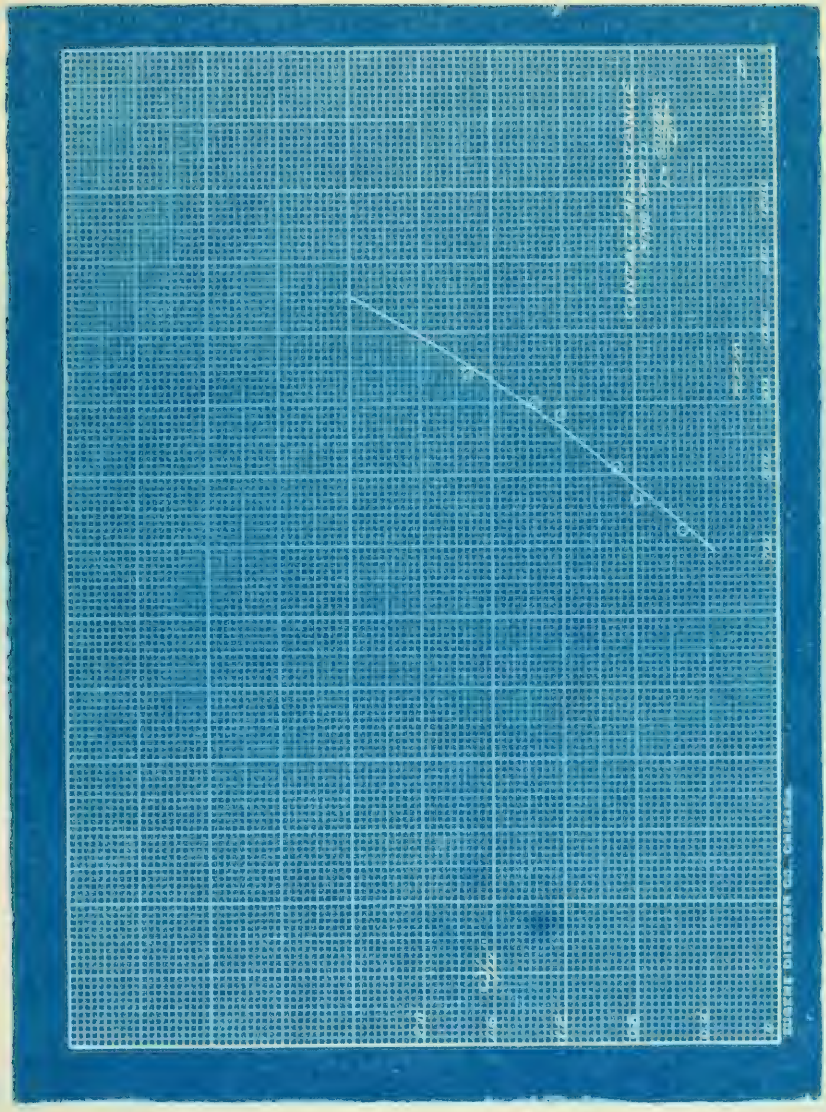
I.	RI.	R.	R/ ".	R.P.M.
10.0	1.1	0.110	0.055	720.
"	1.6	0.160	0.080	765.
"	1.8	0.180	0.090	810.
"	2.4	0.240	0.120	885.
"	2.7	0.270	0.135	900.
"	3.5	0.350	0.175n	945.
9.5	3.0	0.136	0.158	990.
"	2.75	0.248	0.124	1035
"	2.20	0.226	0.113	1080.

#26.

I.	RI.	R.	R/ ".	R.P.M.
9.5	1.20	0.126	0.062	72o.
"	1.70	0.180	0.090	765.
"	1.75	0.248	0.124	810.
"	2.00	0.210	0.105	855.
"	2.30	0.242	0.121	900.
"	3.00	0.316	0.158	945.
"	3.00	0.316	0.158	990.
"	2.75	0.248	0.124	1035.
"	2.80	0/284	0.142	1080.



CONTACT RESISTANCE
1000
1100
1200
EUGENE DIETZGEN CO. CHICAGO


EUGENE DIETZGEN CO. CHICAGO

#27.

Brush #3.

Tens.	R.P.M.	Scale.	K.
30.	800.	16.0	1.41
"	900.	15.0	1.32
"	1020.	14.0	1.32
"	1150.	13.5	1.23
"	1275.	13.0	1.23
"	1425.	12.5	1.19
"	1610.	12.0	1.14

#28.

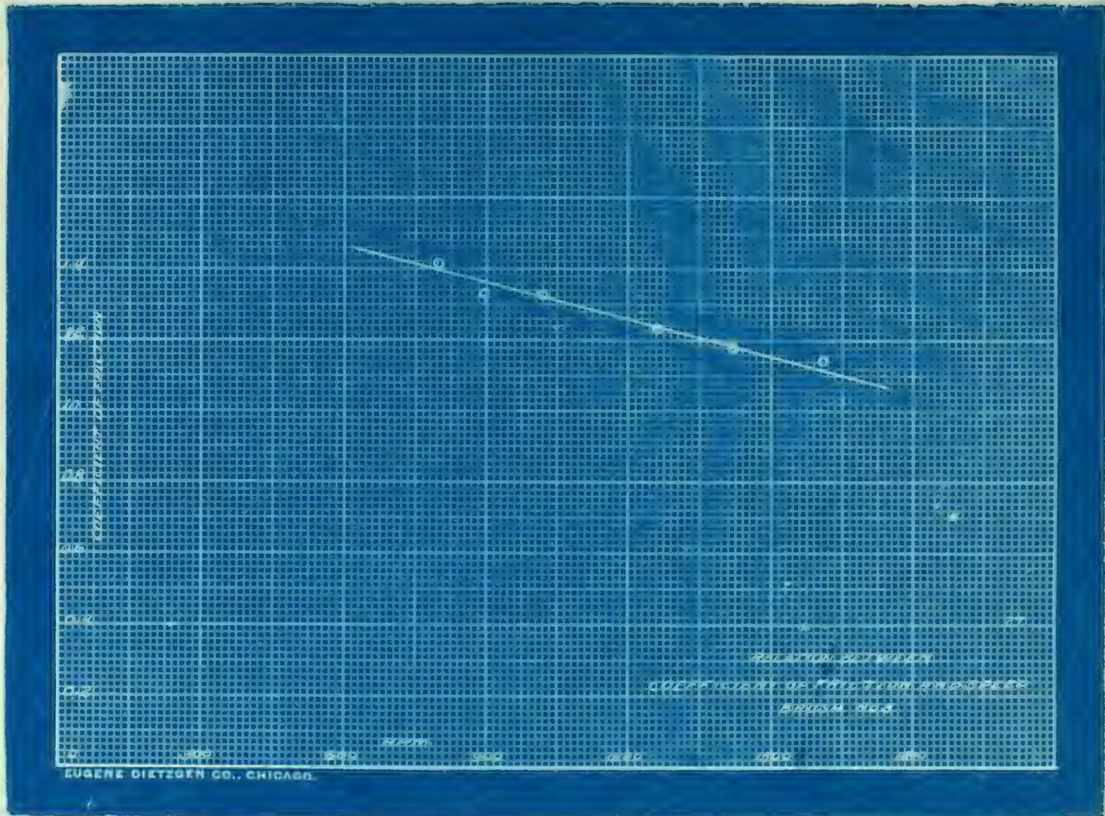
Brush #2.

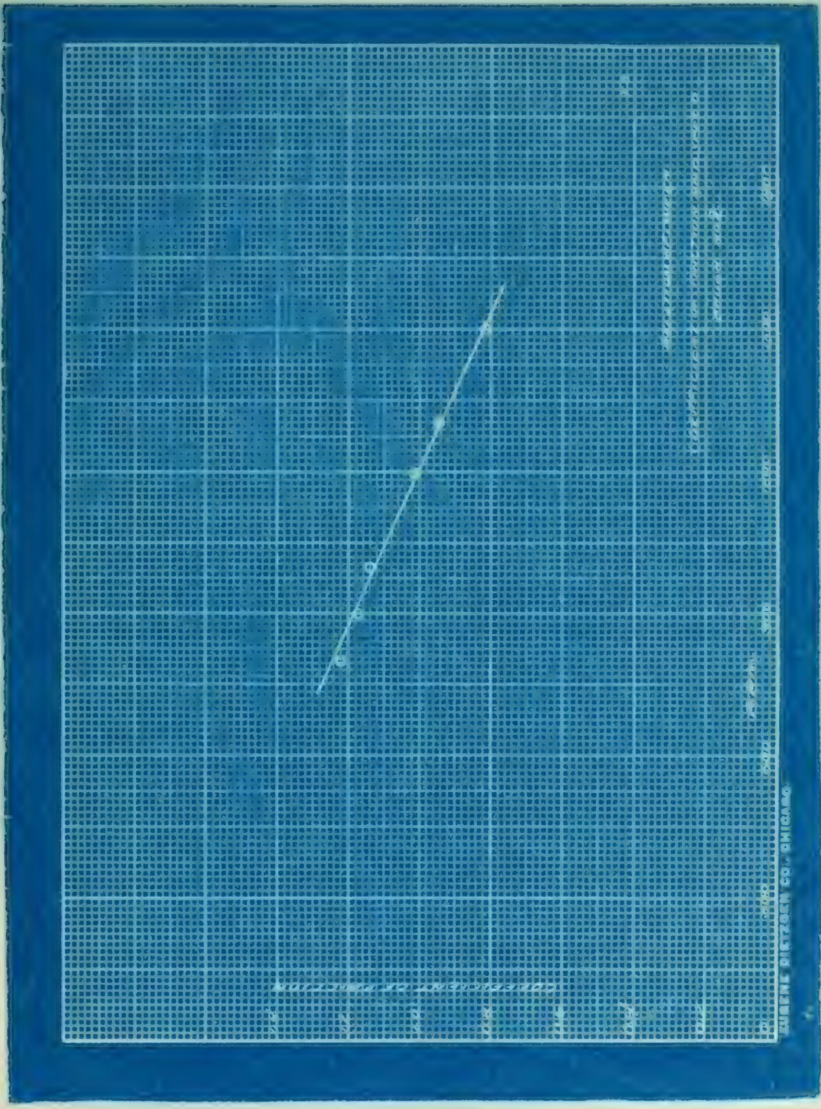
Tens.	R.P.M.	Scale.	K.
40.	800.	18.0	1.21
"	900.	17.5	1.17
"	1000.	17.0	1.14
"	1200.	16.0	1.08
"	1300.	14.0	0.94
"	1500.	12.0	0.81

#29.

40.	1300.	16.6	1.11

(Note) Brush number two was inclined about ten degrees against direction of rotation of commutator.


EUGENE DIETZGEN CO., CHICAGO.



It will be noted in the foregoing curves and data that the contact resistance is not a linear function of either the speed or current density. In the case of the speed contact resistance curves this may be explained from the fact that the impulses which are given by the passing of each segment,occur oftener and are of shorter duration as the frequency of commutation increases. As these impulses occur oftener the spring meets with a greater resistance in restoring the pressure between the brush and the commutator to its origonal value and, as the natural period of the spring is many times the period of the impulses,there is not the same pressure exerted normally to the commutator by the brush as in the case where the frequency of commutation is lower.

Arguing from this stand-point there will be a point at which

the tension of the spring will be balanced against the impulses and no decrease in the pressure of the brush on the commutator will be noticed. This point is shown in curve number one. It was found on others when the speed was carried high enough. In cases where the commutator ran against the slant of the brushes this point occured at speeds much above those used in modern machinery.

The point where a given increment of speed has a minimum effect in increasing the resistance is met at lower speeds where the brush slants in the direction rather than where the slant is opposed to the direction of rotation. This is because in the first case practically all the shock given the brush is taken up in forcing the brush away from the surface of the commutator while in the second case there is a component forcing the brush in the direction of rotation which tends to maintain the pressure between the brush and the commutator. This component also increases the frictional rsistance given to the relative motion of the brush and holder which gives less displacment and is consequently more quickly overcome by the spring.

The fore going may perhaps be made more clear by consideration of figures A and B.

The friction between brush and commutator in both cases exerts a force on the brush in the direction indicated by P.,which in case one will tend to make the brush bear harder on the commutator. In case two the pressure will be somewhat releived. A curve for the condition one is shown on curve sheet number two and in case two is shown on curve sheet number one. The only difference in conditions under which these two curves were made was that of the brush slant.

From these considerations it will be seen that a brush having slant in the direction of rotation is to be prefered in cases where the peripheral speed of the commutator is low. At high peripheral speeds there is but little choice between slant forward and slant backward.

If the slant be opposed a brush holder must be used in which the brush is free to moveand the holder perfectly rigid or the pressure may become so great as to drag the holder around its stud and damage the commutator. When the slant is in the direction of rotation a holder that moves with the brush is to be prefered,for,the brush is then held rigid in two directions and is not so free to "chatter".

The pressure that is added to that of the spring by friction between the brush and commutator makes an error in the coefficient of friction as determined when the machine is running.

The coefficient is calculated with regard to the magnitude of the tension in the spring which is much lower than the actual pressure between the brushes and the commutator. This gives a coefficient that is high in value and differing for diferent slants against rotation but nearly constant and correct if the brush be slanted in the opposite direction.

These coefficients were found by balancing the torque on the holder by means of a spring balance and the forces of friction calculated by taking moments about the center of the shaft of the machine.

The sets of data numbered twenty seven and twenty eight were made with the brush perpendicular to a tangent of the commutator and show that the coefficient of friction decreases in proportion to increase of speed. This is what may be expected if the hypothesis advanced in regard to resistance increase is true. This coefficient as determined with the brush in this position relative to the commutator will be the true coefficient. That in data number 29 was made when the brush was inclined against the direction of rotation and shows conclusively that, in the case where the brush has this position, there is a greater pressure between the brush and the commutator than is given by the spring alone. Calculating backward from the coefficient of fric tion it is found that the increase of pressure is about 15%. The incline of the brush was approximately ten degrees.

The curves made to show the relation between contact resistance and current density are somewhat surprising. At first it was beleived that the decrease of resistance might be due to the temperature changes but after a careful repitition the curves were found to repeat themselves. Constant temperature was obtained in this case by allowing thw brush to carry maximum current at all times except when readings were made. There readings were made as quickly as possible after the current was reduced in order to miniminize any changes of temperature by radiation.

The fall in resistance is greater than could possibly be attributed to the change of resistance in the carbons within the temperature range that was maintained.

This fall in potential might possibly be attributed to an electrolytic action in the infinitessimal air-gap that exists between the carbon and the commutator. In this case we might make the assumption that finely divided carbon forms the conducting medium in the gap and that more is carried from the brush at high currnet densities than at lower densities.

Besides the above given theory there is one other that might be advanced, namely, that there may possibly be a rearrangment of the molecular or atomic construction of the brush. This seems more probable than the former.

If the first explaination be the true one a different resistance might be expected at the positive brush than at the negative one, for a given set of conditions. The potential drop for a constant given current might be a little lower for the positive than that at the negative brush or it might be higher. This will depend on whether or not the "ionizing", as we may term it, of the air gap requires less or more energy than that to overcome the pure resistance of the thin layer of air.

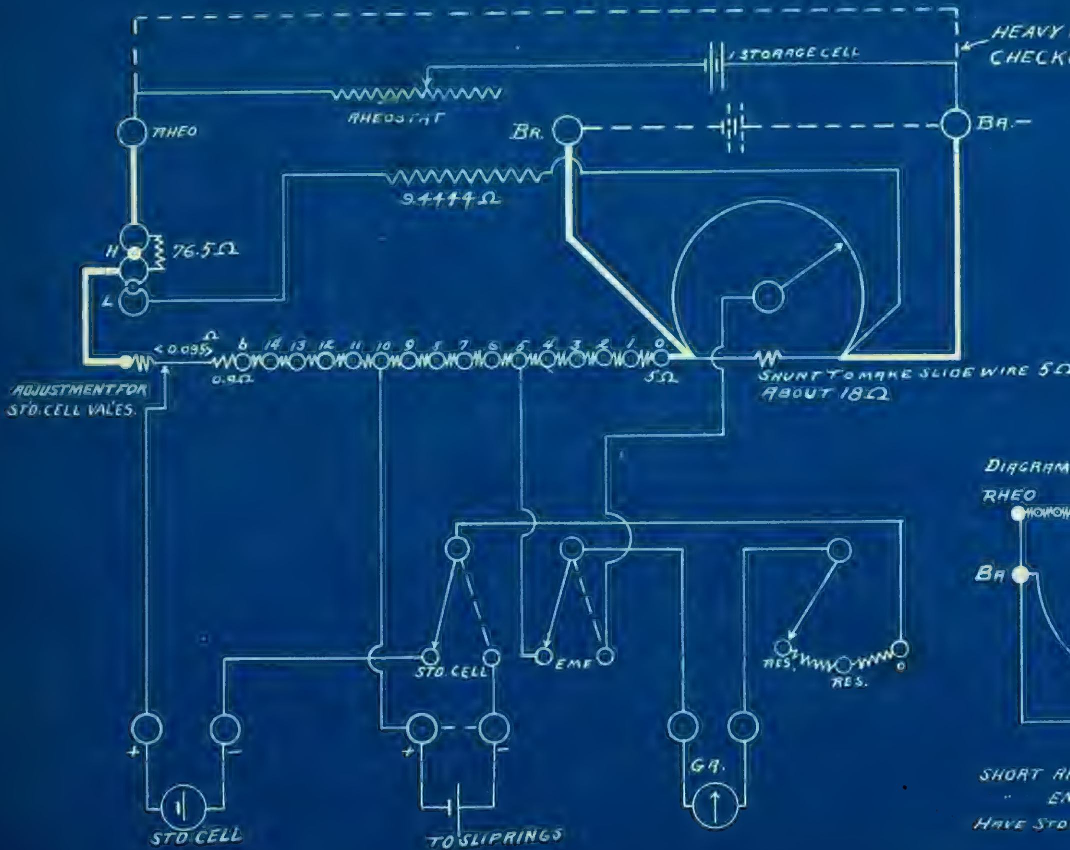
To find if the above mentioned descrepancy it would be of advantage, if not necessity, to use a smooth surface as that of a slip ring in place of a commutator as the difference would be so small that the oscillation of the brush might hide it. Also to get the same conditions when measuring between a negative brush and the ring as when measuring for the positive it would be well to cause the positive brush to become a negative one by simply reversing the current. One terminal of the voltmeter should be attached to the brush and the other to a small metalic strip making a rubbing contact on the surface of the ring. If this method give a consistant difference in the potential drop between a brush and commutator, under constant conditions, when used as a positive and negative electrode we may be justified in saying that there is an electrolytic action

present. If there is no difference we would not be justified in saying that there was no electrolytic reaction as it might be balanced by potential drop at the negative brush, or too small to detect.

In case no difference in the resistance is found when a brush is used as a positive and when used as a negative the question as to whether the change of resistance with current density is due to electrolysis or a rearrangment of atoms is still open.

The curves on sheet number five, made under similar conditions except as to temperature, show a convergence that indicates a limiting minimum value to the resistance. This fact might bear out either supposition that has been made. This change is much greater for a given increment of current at low current densities.

In all the curves plotted for this experiment the resistance for both positive brushes and negative brushes are used as that is the condition found in the actual operation of Direct Current Machinery.



HEAVY DOTTED LINES SHOW
CHECKING CONNECTIONS
1 STORAGE CELL
RHEOSTAT
RHEO
BR.
BR.−
9.4444 Ω
76.5 Ω
H
L
< 0.0955
Ω
b 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
0.9 Ω
5 Ω
ADJUSTMENT FOR
STD. CELL VALES.
SHUNT TO MAKE SLIDE WIRE 5 Ω
ABOUT 18 Ω
STD. CELL
EMF
RES.
RES.
0
+
−
+
−
GA.
STD. CELL
TO SLIPRINGS

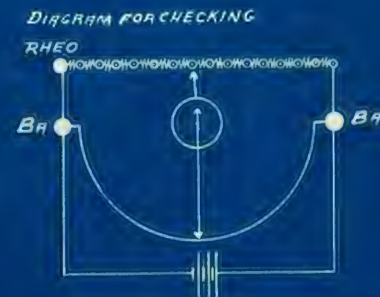


DIAGRAM FOR CHECKING
RHEO
BA
BA.
SHORT Rheo. Post To BA. Post
" EMF Posts
Have Std Cell on EMF

The injury caused by sparking is due to an excessive current in the coil that, during commutation is short circuited by the brush. The object of this experiment is to find the magnitude of this current that flows during short circuit and how is rises at different stages of commutation, how it is changed by change of load, voltage, speed, position of brushes, ect. Also to show what shape it should follow in order that good commutation would result. How can this shape be obtained ?

The scheme for accomplishing this is to measure the fall of potential over one of the end connectors with a sensative galvonometer and a low reading potentiometer.

Slip rings were mounted on the shoulder of the commutator and connected to two points on an end connector, one point being close to the armature and the other at the commutator riser. By using a contact maker the fall of potential over this may be taken for the various positions of the armature coil.

SCHEME:-

APPARATUS:-

Leeds Northrupp Potentiometer.

Weston Reflecting Galvonometer.

Contact-maker.

Standard Cadmium Cell.

Westinghouse Generator. 15 K. W.-115 Volts.-120. Amp.

DISCUSSION:-

The sparking of a generator is caused by a large current in a coil which is necessarily short circuited during the period of commutation. The magnitude of this current depends on the E. M. F. acting in that coil and the resistance of the coil, end connectors, brush, and commutator segments.

The E. M. F. induced in the coil will depend on the speed of the armautre and on the strength of the field it is passing through at short circuit. The field that it is cutting is not only the field of the machine as there is a field of self-induction and a field of mutual -induction as the current in the preceeding coil rises after reversal and as the succeeding coil current falls off before reversal.

The current in the preceeding coil has an effect that, in lap windings is added to that of the following coil. This total may or may not oppose the E. M. F. generated by any of the machine field that may be threading the short circuited coil,

depending on whether the brushes have lag or lead. The E.M.F. of self-induction always tending to prevent a great change of current in any case. In the ideal case the change of current in the short circuited coil will be gradual and nearly a straight line as the current falls to zero from one direction and increases from zero in the other.

This may be realized at slow speeds as the current change is comparatively slow and the inductions, self and mutual, are small. If the coil now be located in a neutral part of the machines field there will be but a small current in the short circuited coil and the current distribution will be governed by Kirchoff's laws and if the current be plotted as a function of time the curve will be much the same as shown in figure.
The greater the reactance of the coil the more nearly a straight line the transition will be. In this case the current density is uniform over all the face of the brush, there is no sparking and the heating of the armature is a minimum.

This result may be accomplished at high speed if the E. M. F. of self-induction and the E. M. F. caused by the machine field are balanced. If the transition be a straight line the E. M. F. of self-induction is constant and for a set of given conditions may be balanced by giving the brushes the right

amount of lead as is done in practice. This however requires a different position for each change of load to secure the ideal case, though in practice one setting, that for full load or rather maximum load the machine is to carry, usuallt gives sparkless commutation though the armature heats considerably. This may be practically neutralized by a resistance in the contact or end connectors, preferably the former, that will give sufficient ohmic drop to keep the current in the short circuited coil within low limits.

On account of mechanical disturbances of the galvonometer it has been as yet impossible to obtain data on this point.